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BULLETIN

OF THE

MUSEUM OF COMPARATIVE ZOÖLOGY

AT

HARVARD COLLEGE, IN CAMBRIDGE.

VOL. XXXIV.

(Geological Series, IV.)

CAMBRIDGE, MASS., U. S. A.
1899.

212989

University Press:
John Wilson and Son, Cambridge, U.S.A.

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June, 1899.

Bulletin of the Museum of Comparative Zoölogy
AT HARVARD COLLEGE.
VOL. XXXIV.
(GEOLOGICAL SERIES, VOL. IV.)

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WITH FORTY-ONE PLATES.

CAMBRIDGE, MASS., U. S. A.:
PRINTED FOR THE MUSEUM.
SEPT. 1899.

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The Geology and Physical Geography of Jamaica: Study of a Type of Antillean Development. Based upon Surveys made for ALEXANDER AGASSIZ. By R. T. HILL.

INTRODUCTION.

JAMAICA presents a more favorable opportunity for detailed geologic investigation than any other tropical area. The authorities have constructed over 4,000 miles of macadamized highways and two lines of railroad across the island in different directions. Bridle paths have been cut to the highest peaks and other points of interest. These public works have made excellent exposures of the substructure, far better than can be seen in most tropical countries. Furthermore, many years ago the English government made, for its time, a most thorough reconnoissance geologic report, and map of the island, which served as guides for the present study, and relieved us of the preliminary drudgery of reconnoissance which ordinarily seriously detracts from the consideration of the higher geological questions in the tropics.

The geology of Jamaica has been studied *in situ* by several writers, the principal of which have been De la Beche,[1] Barrett,[2] Wall,[3] Brown,[4] and Sawkins,[4] all of whom except de la Beche were members of the Official Geological Survey.

De la Beche's conclusions upon the older formations of the island are noted elsewhere. His monograph contains many excellent observations concerning the Tertiary and later formations, which in a degree are more in harmony with the conclusions to be presented by us than the subsequent and more extensive reports of the official surveys which supplanted them.

---

[1] Remarks on the Geology of Jamaica, by H. T. de la Beche. Memoir. Transactions Geol. Soc. London, 1829.

[2] Quart. Jour. Geol. Soc. London, Vol. XVI. pp. 324–326, 1860.

[3] Ibid., Vol. XXI. pp. 1–14, 1865.

[4] Reports of the Geological Survey of Jamaica, London, 1869.

The studies of the island made by the official surveyors were comprehensive and began at least as early as 1859. The official report[1] is the present standard of reference.

The observations and material of the Jamaican survey have also been the bases of several independent papers on the geology of the island, by S. P. Woodward, Moore, Wall, Duncan, and others, which have appeared in the English serials, and which will be frequently cited later on.

Many individuals who have not personally observed the geology of the island have made paleontologic studies of material collected by the survey and others, and announced important conclusions. Among these may be mentioned Moore, S. P. Woodward, Duncan, Gabb, W. J. L. Guppy, Dall, Etheridge, T. Rupert Jones, and Jukes-Browne. So far as minute study and interpretations are concerned, the petrography and physical geography of the island have received little or no attention.

The writings of the authors mentioned have been valuable aids in the preparation of this book. In perusing this literature the reader is constantly impressed with the fact that these researches failed to solve the essential problems of the succession and age of the strata; this fact impaired the value of all subsequent deductions, and fundamental mistakes were made which have had wide bearing on the interpretation of Antillean history. The literature of no other region, especially that relating to paleontology, presents so many erroneous conclusions. To avoid constant corrections of these mistakes, it is best to point them out at the beginning. It is but fair to state that this unfortunate stratigraphic confusion was not the result of incompetence, but was due to an act of Providence. Mr. Lucas Barrett, the Scientific Director of the Official Survey, who alone knew the combined results of its several workers, and was able to correlate them, was drowned in a diving bell while carrying on his studies.[2] Conflicting endeavors to make posthumous interpretations of his opinions were the sources of the subsequent erroneous conclusions.

The official report is a peculiar and unfinished composite, Barrett's death having occurred before its publication. The introduction of two pages is by Sir Roderick I. Murchison. The first general summary of the island is by James Gay Sawkins. Individual reports of the different parishes are by Barrett, Wall, Sawkins, Lennox, and Brown. The Appendix contains a discussion and résumé of the paleontology and age of the rocks of the Caribbean Sea by Robert Etheridge, with paleontologic determinations by Duncan, Carrick Moore, T. Rupert Jones, and others.

---

[1] Entitled "Reports on the Geology of Jamaica, or Part II. of the West Indian Survey," by James G. Sawkins, with contributions by G. P. Wall, Lucas Barrett, Arthur Lennox, and C. D. Brown, and an Appendix by Robert Etheridge, Paleontologist of the Geological Survey of Great Britain, printed for Her Majesty's Stationery Office, 1869, 339 pages, with Maps and Plates. This work and its parts will be frequently referred to in this paper as the Jamaican Reports.

[2] December, 1862. See Obituary Notice in the Geologist, Vol. IV. pp. 60–62, 1863.

In the reports upon the individual parishes each field worker used an independent and often conflicting nomenclature for the various formations described, and frequently expressed contradictory opinions concerning the age of the same formations. For instance, as has been pointed out by other writers[1] with respect to the age of the White limestone, "the reports of the surveyors are inconsistent with one another. In some places (as on pp. 23 and 149) it is called Miocene; in others (pp. 29 and 30), Pliocene, and in the tabular view at the end of the volume it is labelled Post-Pliocene." This confusion is equally apparent concerning all other formations discussed.

The report is deficient in local stratigraphic sections by which the discrepancies might be corrected. On the other hand, the parties who attempted to correlate and generalize the individual reports in the Appendix went to the other extreme, and reduced the nomenclature to a compact but an illogical arrangement. In general, the descriptive portions of the report are fair, but its conclusions concerning the classification, sequence, and age of the rocks leave the reader in a state of confusion.

We cannot point out all of these discrepancies; a comparison of the three summaries given in different parts of the volume will sufficiently exhibit them.[2] The chief confusion resulted from the attempt of those who wrote the summaries to include the various formations of the local observers under certain broad generic terms, such as the "White" or "Yellow" limestones, whereby the whole succession and age of these rocks, whose correct interpretation is most essential to an understanding of the geological history of the island and the Antilles, was confused.

These errors resulted from erroneously correlating the Eocene Yellow limestones with the Miocene (old usage) Bowden beds. The former occur at the base of the entire series of White limestones, and the latter near the top of the same.[1] Furthermore, in this mixture the erroneously combined group was given the stratigraphic position of the Yellow limestones below the White limestones, and the age position of the Bowden beds. This resulted in making all the White limestone, much of which is pre-Miocene, appear as overlying the Bowden Oligocene. As this error has had far reaching importance in obscuring Antillean geology and paleontology, we give a brief sketch of its origin and history.

---

[1] Jukes-Browne and Harrison, Jour. Geol. Soc. London, No. 190, Vol. XLVIII. p. 219.

[2] Jamaican Report, pp. 128, 186–189, and table at end of volume.

The following section,[2] showing the sequence of the Jamaican formations, was published by Woodward in 1862, seven years before the appearance of the official reports in 1869, as a posthumous interpretation of Barrett's conclusions as he (Woodward) understood them. The names on the right are those to be used by us for the equivalent beds of the section. The sequence of the formations, as given in this section, corresponds more nearly with their true occurrence than any of the subsequent compilations to be noted.

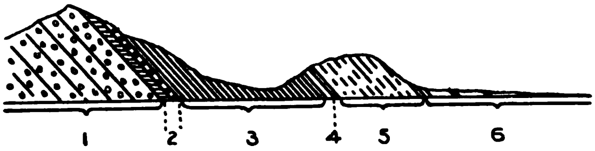

Figure 1. Woodward's Interpretation of Barrett's Section of the Jamaican Sequence.

Barrett's Section.	*Equivalent Nomenclature of this Paper.*
6. Pliocene Limestone and Marls,	Bowden and other Beds of the Coast Series.
5. Miocene Limestone,	*Oceanic Series.*
4. Orbitoidal Limestone,	*Cambridge Beds.*
3. Gray Shales,	*Richmond Beds.*
2. Cretaceous Limestone and Hippurites,	Blue Mountain Series.
1. Purple Conglomerate.	

This original section, supposedly by Barrett, in addition to giving the position of the Hippurites limestone, from which Orbitoides and Nummulinæ were reported, gave in its correct place, under the name of Orbitoidal limestone but without age designation, the beds called Yellow limestone by Brown, which we shall call the Cambridge formation. Woodward, in the text, accidentally no doubt, omits to mention this important formation, and erroneously states[1] that the shales, No. 3 of the figure (our Richmond Beds), are followed by the White limestones of "Miocene age." For verification he refers to a previous article by Barrett,[2] in which we can find no mention of any such sequence.

---

[1] The Bowden formation, although one of the most important in the Jamaican sequence, and the one from which all of the alleged Miocene fossils of Jamaica have come, seems not to have been clearly defined or understood by these earlier writers, — probably because of their supposed identity with the Yellow limestone. See further details, pages 82–84 of this paper.

[2] The Geologist, London, 1862, Vol. V. p. 373.

Later, T. Rupert Jones also published an illustration of a geological section which he said had been given to him by Barrett, "whose unfortunate death had then recently occurred." This section, like that given by Woodward, shows the stratigraphic position of the Orbitoidal limestone, *b*, (called "Nodular Orbitoidal Limestone,"[3] — our Cambridge Beds), between the black shales (Richmond) and White limestones. In the legend of the section the age of the Orbitoidal formation is given by a bracket as the "Miocene." This is the first section in which the Orbitoidal limestone (our Eocene Cambridge Beds in part) was referred to the Miocene. In the same section the overlying White limestones, *a*, which we will show embraces formations of the Vicksburg Eocene (old usage, — called Miocene in Woodward's paper previously alluded to) is referred to the Pliocene. Jones states that "he understood Mr. Barrett to have referred the great "White limestone" to the Pliocene.[4]

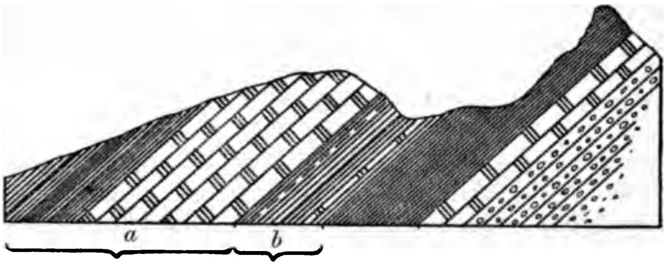

FIGURE 2. T. Rupert Jones's Interpretation of Barrett's Section of the Jamaican Sequence.

In 1864 Duncan and Wall wrongly correlated the Yellow Eocene Orbitoidal limestones at the base of the White limestones with the Bowden beds (Oligocene) which occur above them, and referred the whole to the Miocene. They emphasized this conclusion by speaking[1] of Barrett's "determination of the Miocene age of the coralliferous sands and shales at the base of the great inclined limestone." We can find in literature no substantiation of this alleged assertion of Barrett, and it is not in harmony with his sections as given by Woodward and Jones. These writers were no doubt misled by the superficial resemblance of the upper beds of the Blue Mountain Series to the Bowden conglomerates into considering them identical.

---

[1] The Geologist, London, 1862, Vol. V. p. 373.

[2] "On Some Cretaceous Rocks in Southeastern Portion of Jamaica." Quart. Jour. Geol. Soc. 1860, Vol. XVI. pp. 324–326.

[3] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. p. 515.

[4] Ibid., pp. 514, 515.

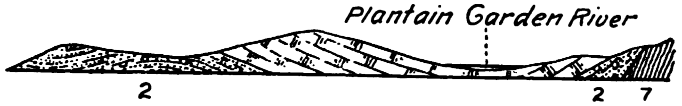

FIGURE 8. Duncan and Wall's Section of the Jamaican Sequence. 1. White Limestone. 2. Miocene Marls and Sands. 7. Altered Conglomerates and Cretaceous Rocks Mixed with Dikes.

In the same paper Duncan and Wall, by the figured section[2] reproduced herewith, completely obliterated all conception of the true position of the Bowden formation by erroneously making it stratigraphically continuous with the Cambridge Yellow limestone beds. In 1896 we personally restudied the section between Bath and Bowden, and found that the relations of the beds had been wrongly given by these writers, and that the Bowden beds, instead of being continuous with the Cambridge beds, were separated from them by all the lower White limestones as shown in the following section.

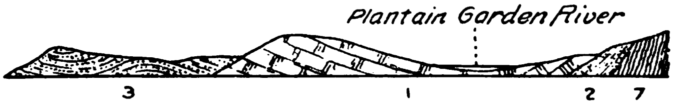

FIGURE 4. Correction of Duncan and Wall's Section of the Jamaican Sequence.

These errors, as published in the English serial literature between the dates of the official field work and the publication of the final report, were perpetuated by Etheridge in the Appendix of the latter work. On page 203, our Cambridge beds — which are so well described in the individual reports upon the western parishes under the heads of "Yellow Limestone" and "Calcareous Marls" — are correlated by him with the Bowden beds, and discussed with them (and perhaps other formations)

[1] Quart. Jour. Geol. Soc. London, 1865, Vol XXI. p. 2.

[2] Ibid., p. 6.

as a single formation under the vague head of the "Miocene." Furthermore, the precedent of not specifying the locality from which the fossils came was followed in all the subsequent paleontologic literature of Guppy and others, and by Dall,[1] who referred the rocks of Jamaica, included by the others in the Miocene, to the Oligocene.

Thus the true sequence of the Jamaican strata was confused in early literature; the proper place of the Cambridge beds (the true Yellow limestones of the west), at the base of the White Limestone Series, appeared for a brief moment, next to be obliterated by erroneous correlation with the entirely different and higher Bowden beds of the east, and all conception of the position and age of a greater part of the great White limestones which mostly lie between them was destroyed. This confusion has become so confounded in the passing years that the present state of knowledge to be derived from the literature is chaotic. Not only after reading the geologic literature of Jamaica, but after going over the island with these reports in hand, the opinion already expressed by others[2] is emphasized, that "clearly there are many interesting questions in the geology of Jamaica which are awaiting further investigation, and the mutual relations of these white marls and limestones is not the least important of them." To straighten out this entanglement will be our earnest endeavor.

It is but justice to say concerning the volume of official reports, that, despite their discrepancies, they are full of valuable uncorrelated data. Although unintelligible to one who has not studied the island, we do not hesitate, after two years of careful study of its pages and the localities of which they treat, to say that by careful re-editing, including the correlation of the observations on the various parishes under a uniform and systematic nomenclature, and striking out much of the Appendix, the volume could be made a valuable guidebook of Jamaican geology. The writer appreciates the worth and value of the individual reports, and acknowledges that they represent important steps in the progressive research which contribute to the ultimate solution of the problems, and that the following pages would have been impossible without them.

In view of the complications presented, and in the light of additional knowledge in the present paper, the formations will be classified *de novo*, with proper credit wherever possible for all previous determinations.

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[1] Proc. U. S. National Museum, Vol. XIX., Washington, 1896.

[2] Jukes-Browne and Harrison, Quart. Jour. Geol. Soc. London, 1896, Vol. XLVII. pp. 190, 221.

Our classification will differ from that of previous writers as follows. In accordance with modern usage, local geographic names will be used for formations instead of lithologic, chronologic, and paleontologic terms, so that where the age or relations of formations are not known, their identity is nevertheless preserved. Hence the terms "White Limestone," "Yellow Limestone," "Trappean Series," "Metamorphic Series," etc., will be abandoned.

Inasmuch as this paper will deal largely with the formations of the Tertiary period, it is necessary briefly to explain the nomenclature to be followed. Until very recently, after the example of Dana, the American Tertiary has been divided into three epochs, the Eocene, Miocene, and Pliocene. Dall has recently adopted the European nomenclature, which accepts a fourth epoch, the Oligocene, interpolated between the Eocene and Miocene, which includes the Vicksburg stage of the Upper Eocene (American usage) and the older beds of the Miocene. Throughout this paper Dall's four divisions, as accepted by him, will be used.

Investigations upon which the present report is based were made in two visits to the island in the winters of 1896 and 1897. These included over eight hundred miles of traverses, with studies of the typical localities of the previous observers, and examinations of excellent new exposures of structure afforded by recent railway construction. Careful study of material in the Museum of the Institute of Jamaica was made, embracing the typical collections of the official surveys. Collections of the rocks and fossils were made wherever possible, and permission was given by the officials of the Institute of Jamaica to borrow such specimens as were desired.

My thanks are due to their Excellencies Governor Sir Henry and Lady Blake, the Governing Board and Professor J. E. Duerden of the Jamaica Institute, Mr. L. Frank of the Jamaican Railway, Mr. Henry Vendryes, Captain Baker and sons, Mr. Arthur James, and many others, for their hospitable aid in our researches.

The following specialists have kindly assisted in a careful study of materials collected: Mr. Whitman Cross, in the study of the petrography of the igneous rocks; Mr. T. W. Stanton, in the study of the Cretaceous and Eocene Mollusca; Mr. R. M. Bagg, Jr., of the New York State Museum, in determining the fossil Foraminifera; Mr. G. B. Shattuck, of Johns Hopkins University, in studying the Cretaceous and Eocene Mollusca.[1] Special thanks are due to Mr. T. Wayland Vaughan for his extensive, thorough, and painstaking studies of the fossil corals, including not only careful examination of all the material in hand, but also personal visits to nearly all the European Museums where the collections of previous workers are preserved. His determinations have been the chief reliance in the interpretation of many obscure points. His studies will be published elsewhere more *in extenso.*

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[1] Mr. Shattuck has been unable to complete these studies for publication in this Report. His results will be presented separately at a later date.

PART I.

Geography and Physiography.

The island of Jamaica is situated between North Latitude 17° 40′ and 18° 3′ and West Longitude 75° 10′ and 78° 23′. Its northern shore lies almost due south of the western half of the Sierra Maestra coast line of Cuba, from which it is 65 miles (nautical) distant. Between these islands lies the eastward prolongation of the great Bartlett depression, 3,000 fathoms deep. The eastern coast is about the same distance from Cape Tiburon, the western point of the island of Haiti, and is separated therefrom by 1,000 fathoms of water. On the south lies a wide stretch of the Caribbean, 2,000 fathoms deep. Cape Gracias á Dios, the nearest Central American land on the western coast of Honduras, is 780 nautical miles distant. Between the Isthmian-Honduran continental littoral and Jamaica extends the Rosalind and Pedro Banks, less than 500 fathoms deep, which constitute an extensive shallow submarine platform, indented at one place by a narrow submarine strait of less than 1,000 fathoms.

Jamaica is almost the exact centre of the great American Mediterranean. By drawing straight lines through the island, as shown in Figure 5, from Galveston to the mouth of the Orinoco, from the southern point of Florida to the northern part of South America, from the eastern end of the Antilles (St. Thomas) to the western indentations of the Gulf of Honduras, and from the most northern Bahama to the Gulf of Atrato, the central position of the island will be apparent, for it will be found at the point of intersection of these radiating lines and about equidistant from their termini. This central position of the island is important from geographic, biologic, and geologic points of view, and makes it a typical base of study for one interested in Antillean problems. Like a measuring gauge set up in the middle of a stream to record the rise and fall of a river, it stands in the centre of the American Mediterranean, — a standard geological index of the great oscillatory changes of level which have taken place in the history of Tropical America, whose feebler amplitudes only are indicated in the perizonal continental borders.

The extreme length of the island is 144 miles, its greatest width is 49 miles, and its least width is 21½ miles, from Kingston to Annatto Bay. The longest axis lies in east and west directions. The outline of the island which encloses 4,207½ square miles,[1] about one eleventh the area of Cuba and 500 square miles greater than Porto Rico, is an elongated parallelogram whose corners have been obliquely truncated, resulting in a wide oblong central area from whose east and west ends project two broad peninsulas.

At first glance, the outline does not appear to have any peculiar meaning, but when analyzed in connection with the geologic structure and adjacent submarine topography, it is of great significance. An interesting feature of this outline is that, while the major trend of the north coast and the island as a whole is east and west, nearly one half the coast line is diagonal to this cardinal direction. The northwest and southeast trends are survivals of the earlier days of Antillean history. The predominant east and west directions are produced by a later geographic revolution.

Configuration. — The relief of Jamaica is dominantly mountainous, for the interrupted Coastal Plain constitutes only a narrow fringe around the island. The first distant view from the east shows a group of mountain summits rising above the expanse of sea in a tangled mass, apparently without systematic ridges or secondary types of relief features by which its configuration can be classified. The higher summits of this end are usually, if not always, veiled in clouds, so that only the lower half of their slopes is ordinarily visible. The mists are apparently forever present in the upper regions. As the coast is more closely approached and the island encircled, the configuration resolves itself into differentiated forms, presenting four distinct and easily recognizable major types and numerous secondary modifications, which will now be explained. Its chief features are: (1) the interior mountain ranges constituting the nucleus of the island; (2) an elevated limestone plateau which surrounds the interior mountains, and ends abruptly towards the sea; (3) the coastal bluffs or back coast border of the seaward margin of the plateau; and (4) a series of low, flat coastal plains around the periphery of the island between the sea and the back coast border. The relation of these features is shown in the various profiles and sections.

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[1] As given by the Jamaican Land Department.

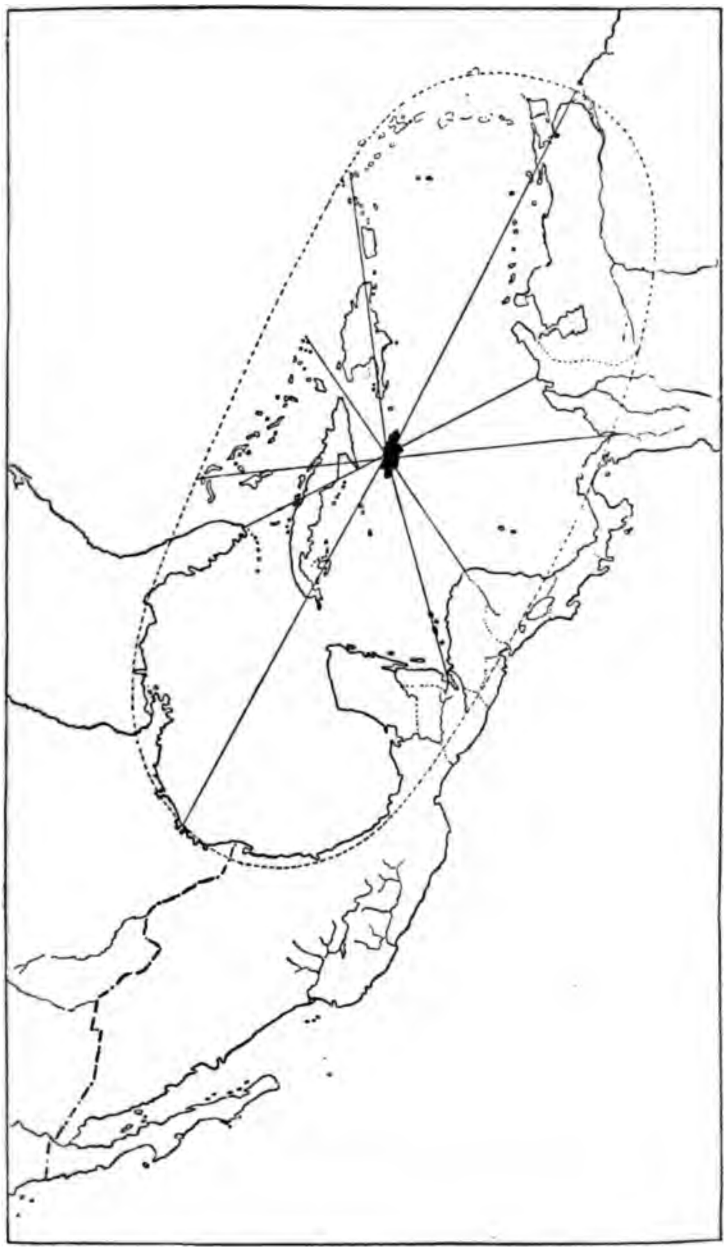

Figure 5. Diagram showing Central Position of Jamaica relative to the American Mediterranean.

The origin of this configuration, which is inextricably associated with the stratigraphic history and geologic evolution of the island, will be more fully explained in the later chapters of this report.

The main mass of the island is an elevated region of rugose relief, consisting of a nucleal mountain range surrounded by a high dissected plateau. The higher region does not slope gradually to the sea, but is terminated near the coast by very abruptly truncated bluffs, steep slopes or benches, usually, but not everywhere, separated from the sea by a narrow strip of plain, as if the original coast margins of the mountainous upland once extended much farther seaward and had been horizontally planed away by the sea's encroachment. The abrupt sea face of the mountainous upland is a marked topographic peculiarity, which we shall call the back coast border. This narrow ribbon of coastal plain is not a continuous belt, but is interrupted, and constitutes an important feature of the Jamaican topography. The secondary features are interior basins and valleys in the summit of the plateau, certain coastal benches and terraces carved out of the margin of the back coast border, and the drainage valleys.

Of these the interior mountains and the limestone plateau are by far the most conspicuous features, and will be first discussed.

The relation of the plateau region to the interior mountains is that of an elongated mesa or bench completely surrounding a higher sierra, the plateau having an outline somewhat like a child's bib, through the neck of which the mountains of the east protrude, surrounded by a narrow collar of plateau, while the main expanse or apron, which lies towards the west, presents occasional views of the buried mountain structure, through rents and holes made by water. The two types of relief of the upland regions are readily distinguishable, even from a great distance, by the entirely distinct physiognomy of their slopes. The interior mountains are marked by deeply etched knife-edged salients (cuchillas) and angular re-entrants which present the aspect of a crumpled handkerchief picked up by the middle, — an illustration used by Columbus in describing the mountains of the Indies to Queen Isabella. These peculiar escabradurate[1] slopes are shown in the illustrations on Plate VI. The corrugations of the Blue Mountain Ridge are plainly visible from Kingston. On the other hand, the hills of the limestone plateau, whether of peaked or flattened summits, present uncorrugated, densely wooded slopes.

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[1] From the Spanish Escabradura, signifying the erosion scratches, — "Bad-land," relief of American usage.

The Mountains of the Interior. — These comprise the Blue Mountain Ridge, which dominates the topography of the eastern third of the island, and certain peculiar isolated summits to the west of the Blue Mountains proper, such as Jerusalem Mountain, Westmoreland, and the Clarendon (Bull Head) Mountains of Clarendon Parish. The isolated groups occur as limited inliers, surrounded and overlooked by hills of the limestone plateau.

The Blue Mountains form a sinuous divide with many bifurcating branches. They extend one third the length of the island, from near the eastern point towards Port Maria, and have a trend of north of west, parallel to the truncated northeast coast of the island. In general, this ridge marks the boundary between the eastern parishes of the north side (Portland and St. Mary) and those of the south (St. Thomas, St. Andrew, and St. Catherine). It presents a serrated crest line with radiating laterals whose summits culminate near the centre of the ridge in the Blue Mountain Peaks (alt. 7,360 feet).[1] West of these peaks the altitudes gradually decrease until they become lower than those of the surrounding limestone hills beneath which the mountain structure was buried in ancient times. Everywhere the ridge and numerous laterals which project from it at right angles present the profile of an inverted letter V, thus Λ. Its configuration is singularly free from benches, mesa tops, or vertical escarpments, the last seldom occurring except as the bluffs immediately adjacent to the present stream beds.

Imagination pictures no more exquisite scenery than that which attends the ascent of Blue Mountain Peak. With increasing altitude panorama after panorama of tropical landscape unfolds in rapid succession. At Gordontown, nine miles north of Kingston, where the interior margin of the Liguanea Plain meets the mountain front, the ascent through the red-colored cliffs of the Hope River Canyon begins, which here, at an altitude of 900 feet, debouches into the gravel plain through a boca. A thousand feet above, the white buildings of Newcastle Barracks look like doves upon a housetop, yet we climb so far above them that they seem like toy houses below. At 2,000 feet the Plain of Liguanea with its city and villages and the shipping of Kingston Harbor, grow smaller and smaller, and finally appear like a diminutive plaza below us. Sometimes our path clings to the side of steep declivities, with an apparently endless slope above and a bottomless chasm below. Again, it follows a knife edge from which we can see beyond, on both sides of the island, the waters of the Caribbean, so distant and so far below that no horizon can be distinguished where the gray of the sea meets that of the sky. Still higher, the forest covered summits of the limestone plateau, with its rugged back coast border, appear below as an unbroken meadow.

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[1] Altitudes given in this report are mostly from the Jamaican surveys.

Each step of the way is marked by wonders of the vegetal kingdom. At the foot is the semi-arid south coast chapparal with exogenous banana plants, cocoanut trees, native cactus, and acacias. Ascending Hope River Canyon the delicate deciduous flora of the island begins, while the cliffs are burdened with ferns — golden, silver, and delicate maidenhair — besides numerous little flowers which find foothold in the rocks. From 1,000 to 4,000 feet, plantations of coffee are numerous, finding congenial temperature and moisture. At 4,000 feet the government has found environment for its cinchona farm. Above 6,000 feet, in an atmosphere of perpetual humidity, tree ferns set in. In this tropical climate such alpine heights offer no obstacle to human environment, and to an altitude of 4,000 feet the slopes are well populated.

There are many other conspicuous peaks of the Blue Mountain Ridge, but few of them have received local names. Sugar Loaf Peak, which lies just east of Blue Mountain Peak, is a part of the latter. To the west are Sir John's Peak, John Crow Hill,[1] Silver Hill, and St. Catherine Peak (alt. 5,036 feet). These high summits are situated near the central portion of the main ridge, which is crossed by five passes with altitudes varying between 3,000 and 4,000 feet.

East of Kingston there are few practical openings through the Blue Mountain ridges which are passable on horseback. One of these is that of Cuna Cuna, between Port Antonio and Bowden, and traverses some of the most rugged and beautiful scenery on the island. Its altitude is 2,698 feet. A good highway crosses the island through a pass in the ridge cut by the waters of the Agua Alta (Wag Water) between Kingston and Port Maria.

Westward from St. Catherine Peak, almost due northeast of Kingston, the main ridge bifurcates; the southern and larger branch continues in a sinuous but generally northwestern course through St. Andrew, where it is known as the Ram's Horn Ridge, and "Above Rocks," and on between St. Mary and St. Andrew as Goddard Ridge, to the drainage divide of Rio Doro and Trumbell's River, near the line of the Port Antonio Railway. Several other ridges radiate from St. Catherine Peak to the northwest in palmate arrangement. All these branches, representing the western end of the Blue Mountain ridges, terminate on the eastern side of the great basin of St. Thomas-in-the-Vale.

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[1] Not to be confused with the John Crow Mountain of the northeast coast.

The mountains are composed of the friable or loosely consolidated shales, clays, and conglomerates of the Blue Mountain Series, with here and there an exceptional local bed of limestone or an occasional dike or mass of igneous rock usually decomposed, all of which are intensely plicated and folded. Their present configuration is due to the readiness with which they yield to erosion. When one considers how rapidly degradation is going on and has gone on, he can only conclude that the mountains were once of much greater altitude and extent. There is no reason why its summits in times past may not have extended as high as their kindred in the Sierra Maestra of Cuba, over 8,000 feet, or in San Domingo, over 10,000 feet.

These Blue Mountains are the highest of an extensive system of corrugations which were partially buried, especially west of the centre of the island, during a former period of subsidence, beneath the veneering of white limestone, and which has since been re-elevated to a height of 3,000 feet. Only the Blue Mountain ridges persisted as land during this epoch of subsidence, while the Clarendon and other westward groups were covered by the ocean's waters.

The old Blue Mountain structure and material reappear in many places in the great central valleys of St. Thomas-in-the-Vale, Clarendon Parish, Great River, and elsewhere to the west, where the later crust of the White Limestone Plateau has been worn away. It is also seen in the face of the back coast bluffs along the western half of the north side of the island below the limestone and above the narrow coastal benches. These were originally a part of the same grand system as the Blue Mountains, which were buried beneath the white limestones, and are now re-exposed by erosion of the latter. Let us examine some of these localities more closely.

The Clarendon Mountains. — The exact geographic centre of Jamaica is marked by a most interesting topographic feature, an anticlinal valley worn out of the crest of the low arch of the White Limestone Plateau. This is an elongated oval area, fifty miles in length, lying mostly in Clarendon Parish, but extending on the southeast into St. Catherine and on the northwest into Trelawney. This great amphitheatre is completely surrounded by the inward facing breaks of the Limestone Plateau, which rise 2,558 feet on the south and 3,000 feet on the west side. Most of the area of the valley is occupied by two parallel mountainous ridges with laterals and disconnected outliers. The most southern ridge

— the drainage divide of the Minho and St. Thomas — is known as the "Main Ridge." The other, which lies between the drainage of the Minho and Cave and Pindars Rivers, may be called the Santa Maria Ridge. It culminates eastward in Bull Head, an elongated summit. A view of the latter mountain is shown on Plate VII. These ridges consist of the same material as the Blue Mountain Ridge, present similar slopes with cuchillate salients, and differ only in their crests, which are not so serrated. They have a general north of west trend, parallel to that of the Blue Mountain Ridge. They are not continuous with the latter, whose west end terminates *en échelon* many miles northeast of where the former begin.

The present relief of these ridges, while greatly resembling that of the Blue Mountains, has been produced during late epochs by the deep erosion of the river valleys which are parallel to them. The heights of these mountains (Bull Head, 2,885 feet, and the main ridge, 2,542 feet) do not anywhere exceed that of the circumscribing White Limestone Plateau. It is our opinion that they are merely modern drainage divides, their summits representing an older floor of a former central basin valley like those described on later pages. Furthermore, the data indicate that this older and higher floor was once completely covered by the formations of the White Limestone Plateau.

In the southeast corner of Hanover Parish, in the valley of Great River, at Jerusalem Mountain in the north central portion of Westmoreland and along the northwest coast of Hanover, the Central Mountain rocks and structure are again exposed by denudation of the once overlying white limestone sheet as in the Clarendon district. Jerusalem Mountain is a hill 600 feet above the plain, surrounded by an amphitheatre of white limestone hills. The other exposures are usually shown in the valleys of streamways. Probably the Great River and Jerusalem Mountain localities represent exposures of a third line of old mountain folds lying south of the Clarendon trend.

In all the localities mentioned, the Central Mountain structure is intensely folded. In the east it is a crumpled anticline, and has evidently been subjected to the additional disturbance of a later intrusion of a great mass of granitoid porphyry, with many auxiliary dikes, which is now exposed by erosion on the north side of the west end of the ridges in St. Mary. Westward the structure is that of overthrown closed folds, as shown in Plate XXII., which is a view of the structure on the north coast near Lucea. The geologic section further exhibits the deformation which has produced the Blue Mountains of Jamaica.

In general, all the Central Mountain structure occurs along three lines of strike, probably representing the outcrop of two original lines of corrugation, whose ends overlap *en échelon*. One is the Blue Mountain Ridge proper; the others are represented by the buried summits of the west. The Blue Mountain Ridge is the most northern and eastern of these old corrugations, the Clarendon and Hanover exposures an intermediate one, and the Jerusalem the most southern and western.

While the mountain eminences of the Central type nowhere extend to the immediate coast, and are everywhere separated from it by the hills of the back coast country, the mountain structure itself is found in the bluffs on the north coast outcropping at the sea beneath the White Limestone Plateau. From this fact we conclude that, collectively, the Central Mountains of Jamaica represent an ancient mountainous topography, at one time occupying an area larger than the whole of the present island, and, for reasons stated in our final chapter, related to similar features of the other Great Antilles.

The Plateau Region. — This later addition to the original island of Jamaica is now a much dissected plain rising 3,000 feet. Its principal occurrence is west of the Blue Mountains, where it extends entirely across the island. In the east it constitutes a narrow collar or dado of limestone country around the coastward margin of the Blue Mountain Ridge. In all, it occupies fully four fifths of the total area.

As a whole, the profile of the plateau, could the irregularities of erosion be eliminated, would be a very gentle arch, from whose east and west axis the surface slopes towards the adjacent seas. The curves of this arch if continued would not reach the sea at the present truncated margin of the land, but intercept it quite a distance beyond either shore, as shown in Figure 6, indicating that the former borders of the now restricted island were extended. Thus in many places the margin of this plateau is marked by benches and terraces, constituting the back coast borders presently to be described.

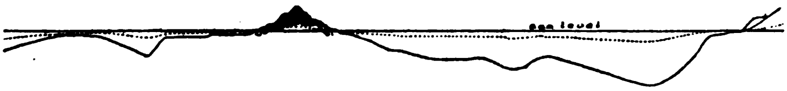

FIGURE 6. Showing Truncated Margins and former Seaward Extension of Jamaica. — Dotted line shows Natural Profile.

By tacit consent, the innumerable eminences of the plateau which rise to nearly 3,000 feet are called hills in Jamaica, to distinguish them from the Central Mountains. The highest summits of the plateau are found in the crests surrounding the Clarendon basin, near the centre of the island, which attain a maximum altitude of about 3,000 feet or less than one half that of the highest Blue Mountain peaks. The highest of the plateau remnants is Mount Diablo, which forms the divide between the two coasts as well as between St. Thomas and Clarendon valleys. It is reported to be 3,053 feet in altitude. Altitudes exceeding 2,000 feet continue southward from the west end of the Clarendon Valley almost to the southern coast of Manchester and St. Elizabeth. Some of these are given by the official surveys as follows: Mocha, 2,558 feet; Cabbage Hall, 2,983 feet; Drayton, 2,210 feet; Sedburg, 2,269 feet; Mason's Run, 3,000 feet; Craig Head, 2,619 feet; Aboukir, 2,019 feet; and Water Mount, 1,844 feet. Don Figuera Mountains, over 2,400 feet, Mile Gully Mountains, 2,514 feet, and Carpenter's Mountain of Manchester, 2,400 feet, are also remnants of this old plateau level, near the south coast of the central region. On the east the John Crow Ridge (alt. 2,110 feet), an elongated summit extending parallel to the coast, may be either a remnant of the old summit level or the oldest and highest of the base level plains cut out of its marginal topography. On the south side of the Blue Mountain Ridge the highest summit of Yallahs Mountain (alt. 2,254 feet) is the sole surviving remnant of the old summit topography of that side of the island. These elevations indicate that the region of maximum altitude of the plateau was in the widest part of the island from near the south coast of Manchester to and just across the boundary of St. Ann.

In places along the south coast there are isolated white limestone remnants of the plateau, which are separated from the main body by the wide indentations of the lower lying Coastal Plains. The Port Henderson and Healthshire Hills of St. Catherine, and the Braziletto Mountains and Portland Ridge of Clarendon, are of this type.

The materials of the plateau and its outliers are soluble limestones, — old sheets of calcareous oceanic sediments now chalky or subcrystalline in texture, which were deposited upon and around the bases of the Central Mountains and attained their present altitude by a subsequent elevation. These white limestones are described elsewhere in this paper under the names of the Montpelier, Moneague, and Cobre formations. The details of the configuration are largely due to the peculiar solvent character of the limestone. These hills, especially in the interior, owe their configuration largely to the agency of solution, while the forms of the Central Mountains are due entirely to denudation. So important and wide reaching are the influences of solution that it must be constantly considered in a discussion of the region.

The summit of the plateau is a roughly serrated hilly country, indented by cockpits (sinkholes), subcircular basin valleys, and deep drainageways leading to the sea. In many places the surface is marked by jagged honeycombed rocks, between which grows a dense tropical foliage. Knife-edged lateral salients, like those which characterize the Central Mountains, are missing from this topography. Steep bluffs, undermining benches, caverns, and sinkholes abound.

The Cockpit Country. — The origin of the ragged summit topography of the White Limestone Plateau, and the evolution of the numerous interior basin valleys of which they are antecedent, can be best illustrated by a description of "the cockpit country," as it is locally called; this, with its modifications, includes the whole of the high interior portions of the parishes of St. Ann, Trelawney, St. James, Hanover, Westmoreland, Manchester, and St. Elizabeth, to the west and north of the Clarendon ridges, although the cockpits are limited to a rough district embracing the corners of Trelawney and St. James. In the interior of the western half of the island the hills are sharply rounded conical points. Towards the coast there are long flat-topped ridges with steep slopes, such as the John Crow Ridge of Portland, Yallahs Ridge of St. Thomas, Long Mountain of St. Andrew, the Healthshire Hills of St. Catherine, the Portland Hills of Clarendon, and others. Still another type are flat-topped circular mesas with steep walls, such as occur in parts of Westmoreland and Hanover.

The cockpits are primarily deep funnel-shaped sinkholes, from which the drainage percolates downward into the cavities and fissures of the underlying rocks. The steep acclivities of these holes ascend into pointed conical hills. Their origin and evolution is shown upon the accompanying figure. The pits vary in depth from shallow circular basin-like depressions surrounded by low mammillary hills (Fig. 7, I) which mark the youthful stage of their formation, to deep-sided sinks often 500 feet in depth, denoting the acute stage of development (Fig. 7, II). Both these types are common on the summit region, where there is no surface drainage, the water settling in pools and penetrating down into the soluble and open textured substructure, carrying with it lime in solution and leaving behind as soil and in the cavities of the limestone a blood red residuum of iron and clay, as may be seen in many fine vertical sections cut along the line of the newly constructed Montego Bay Railway.

The two foregoing stages of the cockpit topography are always developed in the upper part of the white limestones. Below these is another limestone formation of more even texture, still soluble but less pervious than the former, which forms a temporary resistance plane to the progress of degradation. Still below the latter are the nodular limestones, clays, and conglomerates of the older insoluble and impervious formation whose close texture stops the further downward progress of the lime-charged waters which must then find passage in sub-horizontal directions.

When the bottoms of the cockpits reach the temporary resistance layers of the second group of limestone beds (Fig. 7, iii) their perimeters begin to expand laterally, thereby forming peculiar round or oval valleys with steep sides, commonly known in Jamaica as light-holes (Plate IX. Fig. 2). The downward process continues below the lower limestone, first dissecting it into flat-topped remnants, as shown in Figure 7, iv and v, and finally removing it entirely.

When the insoluble beds of the older nucleal mountain material are reached, the cockpit topography enters a period of decadence. Downward degradation by solution ceases; the valleys expand by lateral erosion (Fig. 7, vi) and extensive circular enclosed basin valleys result. Furthermore, great springs of water break out at the contact of the limestones and clays, and establish corrasive drainage, absent in the higher limestone districts, which etches the floor of these basins into miniature mountain forms, thus reviving the ancient antecedent topography. The barriers between these valleys and the coastal drainage are ultimately captured by the latter, and in this manner some of the valleys have become connected with the Coastal Plains of the Liguanea type to be described. Such is the evolution of the topography of the cockpit country and the origin of the interior basin valleys of Jamaica.

The Interior Basin Valleys. — The many basin-shaped depressions occurring throughout the plateau region constitute some of the most interesting physiographic features of the island. Although varying in dimensions, these are all of a uniform type, consisting of deep depressions in the summit of the plateau, enclosed by rugged limestone walls, and having a floor established upon the rocks of the Blue Mountain Series, and are covered by accumulations of alluvium or residual soils. The valleys differ from one another chiefly in area and irregularities of the relief of the basin bottoms which seldom exceed 400 feet in altitude above sea level, while the perimeters of surrounding hills rise from 1,200 to 2,500 feet above them, the height varying in different localities. In

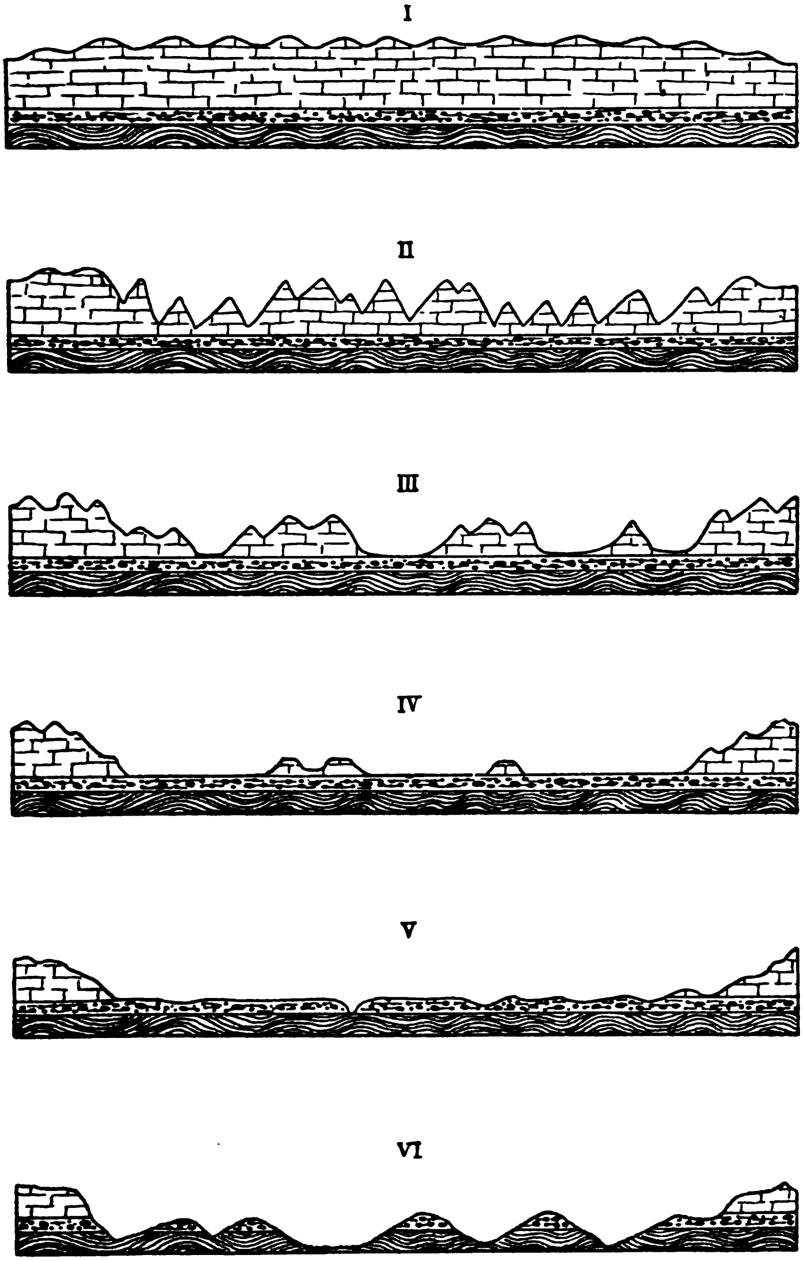

FIGURE 7. Evolution of the Cockpit Topography.

many cases these valleys have no superficial outletting drainage, while in others the barriers have been partially eroded away, and they are drained by rivers leading to the sea.

The largest of these depressions are those of St. Thomas-in-the-Vale, the great Vale of Clarendon, surrounding the Clarendon Mountains, the Hector River Basin in northern Manchester, and the Niagara River Valley along the boundary of St. Elizabeth and St. James. Montpelier Valley along Great River in Hanover, and Morgan's Gut Valley in Westmoreland, are similar basins which have had drainage gaps cut through their surrounding barriers. The latter now constitutes an interior embayment of the great plain of Savanna-la-Mar.

The valley of St. Thomas-in-the-Vale is almost circular in outline and its floor has a diameter of ten miles. Its bottom is largely covered with old alluvium. The mountainous scenery encircling this basin is beautiful beyond description. From Ewarton can be seen a band of white limestone, rising on the west side of the valley in a gentle arch, and extending for miles towards Moneague. This band has a steep face, and is crested by rugged points forming the plateau summit. The culmination of this arch is Mount Diablo, whose summit is 2,500 feet above the bottom of the basin. This valley is drained by about ten copious streams, which gather into a single arterial trunk, the Rio Cobre, by which they pass to the sea through the narrow gorge of Bog Walk Canyon. These streams have their sources in springs or caverns in lower portions of the limestone formation of the hilly perimeter near their contact with the impervious Blue Mountain Series. At one time in its history this valley had no direct outlet to the sea, but connection has been made by encroachment upon the divide by the former headwaters of the Rio Cobre, which was originally a simple marginal coastal stream, and its capture of the basin drainage.

The Clarendon Valley has been partially described in our remarks on the Clarendon Mountains. While this is of the same general type and origin as that of St. Thomas-in-the-Vale it differs from it in details of configuration, chief of which is the fact that the Clarendon Mountains rise from its centre so that the valley proper is confined to an annular area lying between these mountains and the surrounding white limestone escarpments. The Clarendon Valley is about 50 miles in length and 25 miles in width. Its longer direction corresponds with that of the axis of the plateau. The drainage, like that of St. Thomas-in-the-Vale, concentrates into an arterial trunk known as the Minho, through the canyon of which it outlets to the south coast.

The pouch-like basin of Hector River is almost connected with the northwest end of Clarendon Basin. At present the two are separated by a low drainage saddle which has no direct outlet to the sea. The stream from which the basin takes its name rises from springs at its west end, and sinks into the limestones to the east. Cave Valley in St. Ann Parish, is four miles in diameter, and is also almost connected with the Clarendon Valley, but is separated from it by a narrow limestone ridge less than a mile in width.

West of the Clarendon Basin similar circular depressions occur at short intervals, such as those at Oxford, on the boundary of the parishes of Manchester and St. Elizabeth; the great headwater amphitheatre of Black River, St. Elizabeth; the basins of Niagara River, the Mulgrave and Ipswich sinks; the Cambridge Basin; the basins at the head of Roaring River, and the King's Valley Basin near Jerusalem, the last two of which open into the Savanna-la-Mar (Plain by the Sea). Of these the Niagara, Mulgrave, and Ipswich basins have no drainage outlets.

The basins above described constitute a line of depressions along the central axis of the plateau. North of these in the high plateau region of the parishes of Trelawney and St. Ann, are many other basins. The most eastern of these, the Hampshire Valley, is about eight miles in length and averages less than two miles in width. The bottom of this basin barely reaches, if it does reach, the buried Blue Mountain structure, and has an elevation of about 400 feet. The surrounding hills rise 1,200 feet or more. To the west the Hampshire Valley is duplicated in miniature by the Basin Fontabelle. Then comes the Queen of Spain's Valley, a subcircular area five miles in diameter, whose bottom cuts down to within 370 feet of sea level. Only a low gap divides the latter from the great amphitheatre of Sunderland in St. James, which has been captured by the headwaters of the Montego River. South of this is the basin of Maroontown.

There are many other smaller and less important sinks in the western portion of the island, but those we have enumerated show the character of these widely distributed phenomena. From our descriptions it will be seen that many sinks have no outlet to the sea, although in their bottoms may be found limpid streams of water. The barriers of others, like those of Anchovy, Montpelier, Cambridge, and Chesterfield, lying along Great River, have been broken by capturing drainage, become connected with adjacent basins or coastal plains, and found outlets to the sea by the union of several streams. Others, like the Clarendon and St. Thomas valleys, were once entirely enclosed, but in later times have found narrow outlets through single gorges. Still others, like the basin of Westmoreland, have had their coastward barriers largely destroyed. In all, they are interesting features of the decay of the limestone plateau. The entire series of depressions we have described — the first incipient "hog-wallow"-like swales of the plateau, the acute cockpits, the small well shaped sinks of the Hampshire type, the great expanded basins of St. Thomas and Clarendon, and the old basins which have had their barriers partially broken away — are a series of connected phenomena, and illustrate the powerful effect of solution and erosion in producing the hilly topography of the White Limestone districts of Jamaica and the Tropics in general, and in degrading the plateau to the level of the sea. Should the island undergo no more uplift, the agency of solution alone would ultimately entirely remove the white limestones now veneering the older foundation of insoluble Blue Mountain rocks underlying them. Not only has the plateau region undergone vertical disintegration by erosion and solution, but, as will now be shown, its margins have been similarly affected.

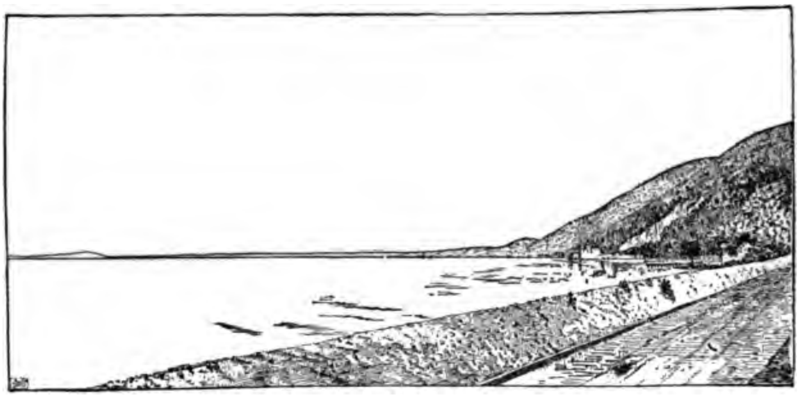

FIGURE 8. View of Back Coast Border from Rock Fort.

Topography of the Back Coast Border. — The former areal extent of Jamaica has been constricted by the horizontal planing away of its seaward margin, as shown by a further study of the back coast topography. This, as distinguished from the narrow strips of coastal plains at its foot, which will be next described, presents a steeply sloping mountainous sea front rising sharply above the sea except where cut through by transecting drainage, and its skyline has an average altitude of 1,200 feet along the north coast.

To the ordinary traveller this back coast topography is principally interesting from its scenic features. To the topographer it reveals a series of most interesting ancient terrace levels, which give important testimony concerning the history of the island. Some of these are beautifully shown on the east side of Montego Bay (see Plate XX.), where six distinct levels or benches separated by deep slopes rise above the sea in stair-like arrangement. At no other single locality are so many of these levels shown in such close juxtaposition but one or more of them can be individually distinguished at many localities entirely around the island, as well as some others as high as 2,000 feet. At a single glance these terraces in Jamaica do not present the perfection of the allied phenomena exhibited on the southeast coast of Cuba, but nevertheless, they record a similar geological history.

Naturally the integrity of these levels varies with their relative age and altitude. Those of higher altitudes are more fragmentary because degradational processes have been working upon them longer. Fragments of the lower benches are better preserved, although much broken by erosion, while none of them are as perfect in contour as the benches of the Coastal Plain. All have been cut across by rivers, etched and dissolved by rainfall, and undermined by encroachment of the waves, so that they are now often indistinct, but there are sufficient remnants in Jamaica to enable the student of geomorphology to recognize them.

Without an accurate topographic survey of the island, it is impossible to correlate correctly all the different benches or to do more than approximate their altitudes. The following general statements concerning them are based upon personal observations. The high sky line of the back coast border, as seen from the sea, in some cases represents the survival of the oldest summit topography of the plateau, and in others benches and terraces which have been successively cut out of it during intermittent periods of elevation. The highest of the old benches is John Crow Ridge, a long narrow shoulder which is seen in approaching the island from the Windward Passage; it projects seaward from the Blue Mountains and extends from back of Northeast Point near Port Antonio southeast to Holland Bay. It may be a remnant of the summit topography of the old plateau level. It is apparently a continuous horizontal plateau composed of several patches of level surface, ending to the southeast with the area known as the "Big Level." The interior or landward side of the John Crow Plateau is now separated from the Blue Mountain Ridge by the tremendous ravine of the Rio Grande. The higher summit of Yallahs Mountain on the south coast (see Plate

XIII. Fig. 2) is also apparently a remnant of the same level as the John Crow Bench, but the writer cannot positively establish this fact as he did not ascend to the summit of this hill. Probably Dolphin Head (alt. 1,800 feet) and other points of Hanover near the west end of the island are remnants of the John Crow level.

The next persistent level traceable in the back coast topography closely corresponds with the altitude of 1,500 feet. This is etched with great clearness upon the outline of the island, being noticeable as the long horizontal sky line of many of the so called mountains of which Long Mountain east of Kingston is a conspicuous type. On the south side of the island this is widely developed at many places, notably at Cambridge Hill (alt. 1,521 feet) west of the Yallahs River; Mount Salas (alt. 1,561 feet); Long Mountain, near Kingston (alt. 1,490 feet); and several localities along the coast of St. Elizabeth and Manchester, and the coast of Westmoreland at Hopeton. Another notable extent of this level is seen to the right of Porus along the railway towards Montego Bay. This general level is not visible in the north coast topography.

The next conspicuous bench has an altitude closely approximating 1,000 feet, the known altitudes ranging from 961 to 1,035 feet. This level is that of a greatly dissected plain, which dominates the summit topography of the back coast country of the north side of the island west of Port Antonio, and out of which all the lower terraces shown in the picture of Montego Bay (Plate XX.) have been cut. These summits called the "North Coast Ranges" are especially characteristic of a wide strip of country in Hanover, St. James, Trelawney, St. Ann, and St. Mary. On the south coast it is well marked, constituting the angular bench of the Yallahs Mountain profile, and a conspicuous ridge to the east towards Morant Bay as shown in Plate XIII. Fig. 2. These benches at the 2,100, 1,500, and 1,000 foot levels, are connected phenomena and represent a distinct stage of elevation in Antillean history.

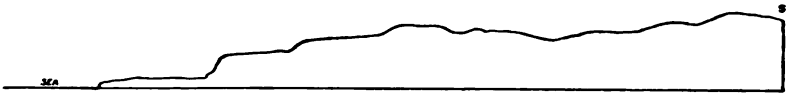

FIGURE 9. Profile, East Side of Montego Bay, showing Benches.

A lower group of bench levels occurs at altitudes of 650, 300, and 200 feet, becoming more distinct and persistent with decreasing altitude. The terraces of the Montego profile shown in Figure 9 mostly belong to the lower group of levels. On the south coast the 650 feet level may be seen in the Yallahs topography, the summit of Round Mountain, at Vere, and the Healthshire Hills west of Port Royal entrance. The 300 foot beach, or Bowden level, is very conspicuous around the east end of the island from Yallahs Mountain on the south to Port Antonio on the north, as well as on the west coast of the north side, at Cinnamon Hill and elsewhere in St. Ann, Trelawney, and St. James.

The back coast benches enumerated have all been cut out of the land by gradational processes (base levelling and marine erosion) and represent pausation stages in two long continued periods of elevation. Those between 700 and 2,000 feet were carved out of the white limestone matrix during the first period of emergence from the sea. The benches, from 100 to 700 feet in altitude are also cut out of the old limestone matrix, but were probably made during a second period of emergence and erosion following a period of subsidence as is explained later on.

This abrupt ending of the land, considered in connection with its accompanying terraces, the arch of the summit region, and the narrow submerged platform around the island, strongly suggests, as outlined in the geologic chapters of this paper, that the Limestone Plateau was once more extensive land, which, after its first elevation, underwent marginal erosion, drowning of its coastal plains by partial subsidence, and re-elevation into its present outline.

From the data given in the geologic portion of this paper, the time of these events was between the beginning of the Miocene (late Oligocene) and Pliocene time. There is much evidence that old gradational terraces of this type continue lower down upon the submerged slopes of the island, and that the phenomena of the Coastal Plain, next to be described, represent veneerings of organic, littoral, and terrigenous deposits upon old erosion planes of this character.

Benches of the Coast Plains. — A narrow strip of low land extends more or less interruptedly around the island, between the sea and the back coast border. In some places this is an old beach only a few feet wide; in others it has greater width and indents the back coast border for miles. This coastal strip is composite in character, being of three types of formations, such as elevated reef rock, marginal sea débris, and land derived alluvium. It presents distinct features of relief, including several benches of different height and origin, and a long and gentle slope known as the Liguanea Plain. The basements of these benches are old erosion levels which were submerged, covered with a veneering of constructional material, and re-elevated into land.

The highest of the benches composed of sea sediments are from 100 to 150 feet. These are well exposed around the east point of the island and along the north coast, where they occur in more or less disconnected patches. The bench at Manchioneal, shown on Plate XVII., is typical of this class. This is a well defined but narrow shoulder projecting from the higher back coast topography, with a vertical sea bluff. At Port Antonio this level is shown at the end of the long peninsula known as Folly Point, upon which the Boston Fruit Company's hotel is situated (Figure 11) as well as in the flat summit of Navy Island, lying a short

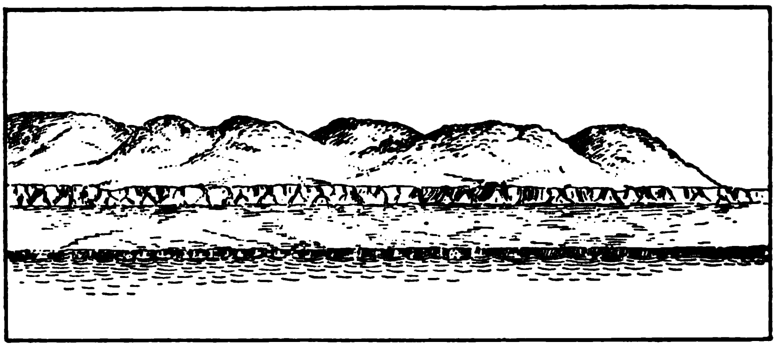

FIGURE 10. Benches of the Coastal Plain, St. James.

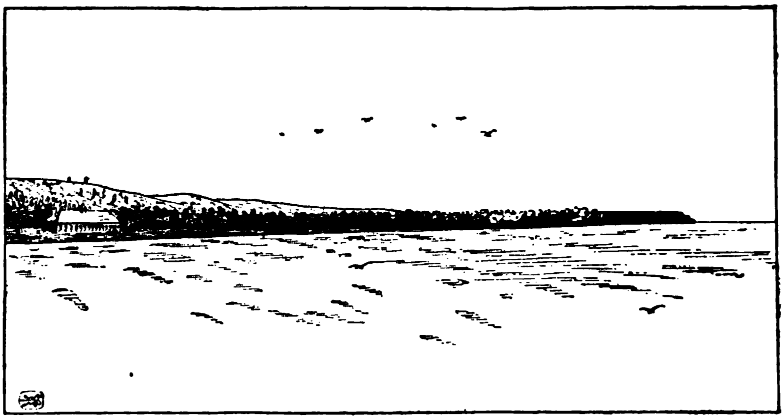

FIGURE 11. Folly Point, Port Antonio, showing Coast Benches.

distance to the west thereof. At Port Maria the same plain is visible both on the mainland and on Cabaretta Island, shown in Plate XIII. Fig. 1, which has been but lately severed from it. This level is largely, if not entirely, composed of the old Pliocene marginal sediments of the sea which have been raised to their present position by epeirogenic uplift.

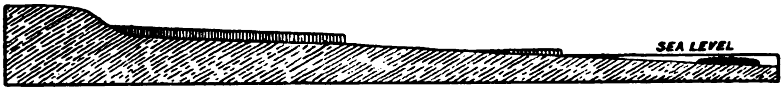

FIGURE 12. Elevated Reefs, North Coast.

The Elevated Reef Levels. — These are more fully described in a later chapter.[1] They are three in number, approximating 15, 25, and 60 feet above the sea, respectively. Only the lowest of these has any considerable extent. These benches are usually composed of single strata, nowhere over 50 feet in thickness, made up of coral heads *in situ* and interstitial débris of the reefs, as they originally grew in the water, upon shallow submerged benches or marginal platforms, similar to those upon which they are now growing around the island, and which have since been brought into their present position by elevation of the island.

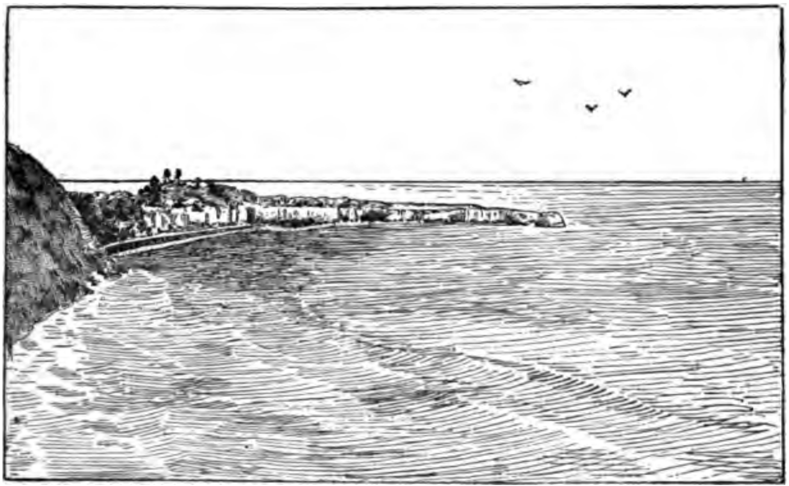

FIGURE 13. Elevated Reefs, Northeast Point.

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[1] These are more fully discussed in the geologic portion of this paper.

The lowest reef constitutes a narrow rugose plain with a precipitous undermining bluff at its seaward margin, as shown in Figure 13, and occurs intermittently entirely around the island tipping the marginal points as seen upon the geological map. The surface is weathered into coarse, cavernous karrenfelder, the so called soborruco.

The lowest marginal plain next to the sea to which this reef belongs is a narrow strip of country seldom exceeding a half mile in width, and occurs nearly everywhere between the water's edge and the back coast bluffs. It is not everywhere composed of reef rock, however. In places it is calcareous sand and marl, which in some instances represent old littoral deposits and in others the débris which may have filled narrow lagoons between the fringing reefs and the coast, and which have been synchronously elevated with the reefs.

Coast Plains of the Liguanea Type. — The coastal plains and slopes covered with alluvium are of a peculiar type, and represent old plains of erosion; they include ancient bights eroded out of the plateau margin, and covered during long epochs of time by gravel and other aggradational land material. The deposits are composite in age, being contemporaneous in some stages of their history with the events of all three of the terrace-making epochs. All plains of this character are not horizontal, but have considerable slope from their interior margins towards the sea, and at least, in the case of Liguanea, much of the aggradational deposits were probably laid down as talus fans. These plains comprise extensive areas indenting the back coast topography, especially on the south side of the island, which is indented by them at eight places. In the eastern portion the plains, like those at the mouth of the Plantain Garden, the Negro, and the Yallahs Rivers, are more elongated and narrow than to the west, where as a rule they are much broader than they are long.

The most extensive of these phenomena is the Plain of Liguanea upon which Kingston is situated (see Figure 8). This is over twenty-five miles in length and averaging six miles in width. This is greatest near its western end in the district of Vere, Parish of Clarendon, where it is about fifteen miles. In all, it includes about 200 square miles. In general, the plain has the outline of a parallelogram, extending in an east and west direction from Hope River and Long Mountain through the parishes of St. Andrew and St. Catherine, to Clarendon Gully, some two miles west of Old Harbor. Its eastern and western thirds border the coast, but its central third, south of Spanish Town, is separated from the sea in two places; at one by the Portland Ridge of Clarendon, which constitutes the southern peninsula of the island, and at another by the extensive outliers of the Limestone Plateau known as the Healthshire and Port Henderson Hills, opposite the Naval Station of Port Royal. The latter are conspicuous features to the west as one enters Kingston Harbor. The Braziletto Hills of Clarendon extend into this plain, almost separating it into eastern and western divisions. The term Liguanea is restricted in local usage to that portion of the plain lying east of this prolongation. The interior margin of the plain terminates against the steep white limestone topography, except just north of Kingston, where it abuts against the Blue Mountain ridges proper. This interior margin is over 800 feet high near Constant Springs, whence it slopes rapidly to the sea at Kingston, six and a half miles distant.

In comparison with regions underlain by other formations, the physical aspect of this plain is arid and sterile. The flora, including thorny acacias and cactus, tends towards the chapparal type so characteristic of the Rio Grande Plain of Mexico and Texas, and presents a striking contrast to the deciduous tropical flora of the remainder of the island. To the west the next extensive plain of this character, known as the Pedro Plain in St. Elizabeth, indents the land to the east and north of Black River Bay. Its estimated area is over 100 square miles. This is analogous to the Plain of Liguanea, except that it contains much marshy ground, and the gravel formation is accompanied by marls. Back of Savanna-la-Mar there is another extensive plain of this type, which continues inward nearly one half the distance across the island. This is cut entirely out of the limestone hills, and, inasmuch as there is little gravel in the back country, the formation is of a marly nature. This plain is fully 100 square miles in area. On the west it is almost connected by a narrow arm with the marshes which border the western coast of the island. Plains of this character are singularly absent from the north side except at Montego Bay adjacent to the mouth of Montego River, where they are more feebly developed than on the south coast.

The history of the Liguanea type of Plains is a record of four distinct events: (1) the original cutting out of the topographic matrix during an antecedent period of base levelling; (2) the filling in of the débris which composes the present surface material of the plains; (3) the elevation of the plains into their present position above the sea; and (4) the cutting of the modern streamways across them. The surface formation of these plains is clearly deposited in pre-eroded valleys carved out of the White Limestone Plateau in preceding erosion epochs which took place during the rapid elevation of the island in Middle Tertiary time. It is evident that during subsequent epochs of subsidence these valleys were drowned and filled with alluvium from the bocas of the rivers which then debouched at their interior margins, and have cut lower streamways through them since the later periods of slight uplift which produced the reef levels.

The frequent occurrence of these plains on the south side and their scanty development on the north side of the island gives rise to a series of inquiries concerning the geographic extent of the island at the time of their formation. It might at first appear that a more extensive land area existed to the northward than at present, but on closer examination this hypothesis is untenable. The greater development of these old valleys on the south is due to the fact that the east and west axis of highest elevation lies nearer the north coast than the south, and the principal slope has long been in the latter direction. An intimate topographic relation exists between the aggradational plains of the coast and the large central basin valleys, and they present synchronous and parallel stages of development. In later times the two have been united in several places by headwater erosion, as shown in our discussion of the basins.

Drainage. — The drainage of Jamaica is peculiar, that of the Blue Mountain districts being frequent and constant in occurrence and copious in run-off, while in the region of the Limestone Plateau it is superficially somewhat deficient in streams which are largely of an underground nature. As a whole, the island presents two major types of streams, one of simple autogenous rivers flowing to either coast, and the other of the streams of the interior basins which have no outlet to the sea ; a third and more complicated type of drainage, a combination of the two preceding, has been produced in certain instances by the capture of the second by the first type.

The rivers of the eastern third of the island divert to either ocean from the Blue Mountain Ridge. This drainage is mostly normal to the coast, with the exception of the Rio Grande of the north side, the Negro River of the south side, Plantain Garden River of the east coast, and Yallahs River; these are probably the most ancient members of the system, and flow for a large portion of their distances in directions subparallel to the main trend of the Blue Mountain axis, that is, in northwest and southeast directions. The streams of this region are marked by deep V-shaped canyons in their upper courses and great deposits of ancient alluvium in their lower parts. The run-off is constant, but variable in quantity owing to torrents. The wide alluvial filled valleys of the Liguanea type, through which the lower portions of the streams now cross to the sea, indicate the following episodes of history: — The bights occupied by the plains were once headwater amphitheatres from which the streams flowed out across a wider coastal border than the present. This extended margin was subsequently drowned by subsidence, so that the original headwater amphitheatres became estuaries indenting the coast into which the streams then debouched. Finally, elevation extended the headwaters of the streams, partially reclaimed the Coastal Plain, and revived the old lower channels or established newer courses across them to the sea.

The drainage of the White Limestone Plateau of the western two thirds of the island is both superficial and underground. The former includes the older and longer streams, such as the Cobre, Milk River, Black River (St. Elizabeth), Island River, and New Savanna River of the south coast; Orange River, Island River, Lucea River, Great River, Montego River, and Roaring River of the north coast, which in general present the same history as the streams of the Blue Mountain Ridge. These are ancient streams, which once brought down immense alluvial deposits now forming the material of the Coastal Plains, through which, since the slight elevation of the latter, they have cut newer direct channels to the sea. Others of this class consist of the short, simple, autogenous streams, probably of later origin, which drain from the bluffs of the back coast border, and are especially well shown along the north coast of St. Ann.

A third and entirely different type of streams, found only in the basins of the Limestone Plateau summit region, include the short local streams which rise from springs or caverns near the contact of the White Limestone and Blue Mountain Series. These flow for short distances, then disappear into the ground without having any visible outlet to the sea. Of this type of rivers are the Minho and Rio Hoe near Moneague; Great River in the southeast corner of St. Ann; Pedro River, which sinks at the corner of St. Ann, Clarendon, and St. Catherine; Yankee and Cave Rivers, which unite and disappear into a sink on the border of St. Ann and Clarendon (the latter river is ten miles long); Hector's River, forming the boundary of Manchester, Trelawney, (about as long as the last stream,) sinking at the northeast corner of St. Elizabeth; Hicks River in Trelawney; Pine and Dry Rivers in the northern part of St. Elizabeth; Niagara, Chester, and Tangle Rivers in the southern part of St. James; Cutting-Grass-Spots and Dean's Rivers, Westmoreland; and Content River in Hanover. It is supposed that the waters of these streams, after sinking into the ground, in some instances find underground connection along the contact of the Blue Mountain and White Limestone Series and into the coastal streams. In many cases the headwaters of the marginal streams have captured the drainage of the great interior basin valleys, especially the Minho, Cobre, Montego, Black River, and Great River. This is shown by the fact that the middle portion of these streams, where they cut the White Limestone Ridge between the plains and the central valleys, have newly formed V-shaped canyons containing no alluvial material such as occurs in the interior valleys which they drain and the lower Coastal Plains through which they flow. The topography of Bog Walk Canyon, shown on Plate X., illustrates the character of the more newly made, intermediate, connective portions of this compound type of streams.

Without details of the geologic structure, it is evident from this topographic review that the present land features of Jamaica are of complex origin, and record many past events of uplift and subsidence which have produced different phases of configuration and outline at different epochs of its history.

Summarized, this history involves: —

(1) Two periods of mountain making (including the elevation of the plateau in this category) accompanied by greater expansion of the island than its present area. The first of these has prevalent north of west trends; those of the second are east and west. The profiles of the former are angular, of the latter gently arched.

(2) Two great epochs of subsidence and contraction of the land, alternating with periods of elevation.

(3) Later uniform elevation which added the narrow modern coastal phenomena.

Finally, we may add that the configuration of Jamaica does not cease at sea level, but there is every evidence that the visible portion of the island is only the tip of a more extensive foundation below the level of the sea, which, especially to the south and east, presents terraced features somewhat similar to those of the exposed coast borders, and which indicate that once the island was slightly more extensive than at present.

PART II.

Geological Structure and Sequence.

The geologic formations of Jamaica belong to four great categories, as follows: —

1. A fundamental series of stratified shales and conglomerates (of terrigenous origin), tuffs and other débris of volcanic material (whose source is not apparent) and, rarely, marine limestones and marls, — all of which have suffered great displacement and deformation. This series characterizes the higher mountains and forms the nucleus of the island structure upon or around which all subsequent formations have accumulated.
2. A series of organically derived oceanic material — marls and limestones — which rest unconformably against and upon but do not completely overlap the more elevated outcrops of the first mentioned series. It constitutes piedmontal formations of great thickness around bases of the higher mountain summits.
3. Laccoliths, dikes, and sills of igneous rocks, which penetrate the first series and the lower portion of the second, and are, therefore, of later age than both.
4. Certain deposits of alluvium, oceanic marls, and coral reef rock, which are adjacent to the present coasts and represent fringing reefs and other accretions around the island's border after it had almost attained its present area and outline.

These four series of rocks are uncomformable to one another, and are the products of the greater events in the geologic history of the island. Together with the formations composing them, they are tabulated on the following page.

THE BLUE MOUNTAIN SERIES.

This series comprises the oldest rocks of the island. It consists of loose or slightly indurated beds of gravel, clay, boulders, and tuffs, with exceptional beds or bosses of hard indurated limestones and yellow clay. The rocks are usually of dark color (black, blue, or dull chocolate), in strong contrast to the glaringly light colors which characterize the succeeding formations of the Oceanic and Coastal Series. The material, with the exception of occasional limestone beds and a few outcrops of clay marls, can be traced to igneous rocks; it was first volcanic ejecta and subsequently and successively underwent various degrees of attrition

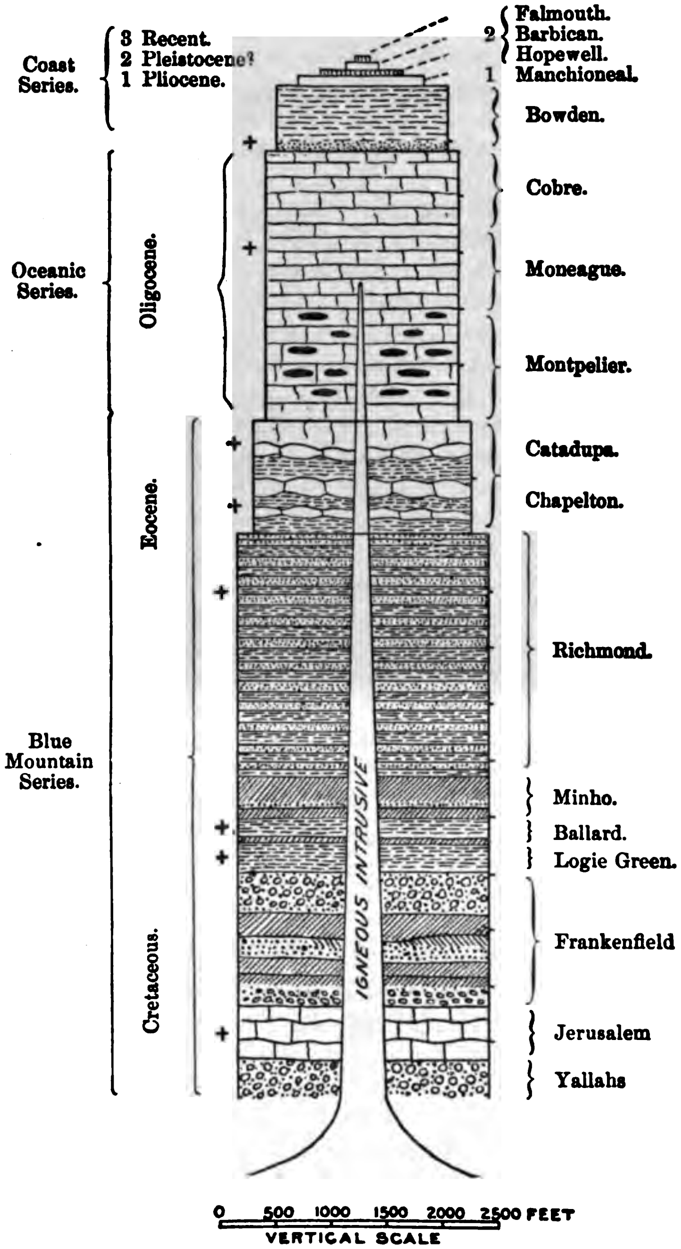

FIGURE 14. Sequence of Geological Formations.
++ Fossiliferous Beds.

and sedimentation from coarse boulders and tuffs to finely triturated impure clay shale, — a process indicating extensive working over. These rocks are the material of the Central Mountains, composing the eminences above 3,000 feet, such as the Blue Mountain Ridge. They undoubtedly underlie the surface rocks of the rest of the island as occasionally revealed by erosion through the white limestone which veneers them, as seen in some of the central basin valleys, the canyons of the marginal streams, and certain bluffs of the back coast border along the northwest coast.

Nowhere on the island can all the beds of the series be seen in continuous exposure. As has been noted[1] concerning the rocks of the Blue Mountain district, "the strata are so excessively disturbed, so traversed and semi-metamorphosed by dikes of syenite and mixed up with porphyritic masses, that it is impossible to observe the intricacies of the stratification or to determine the sequence of the beds *inter se* without a lengthened and detailed investigation." Sufficient is known to state that it probably exceeds 5,000 feet.

Previous attempts to classify the rocks which are collectively arranged in this series have been confusing and unsatisfactory. De la Beche,[2] who first described them in 1828, referred them as follows: "Submedial or Transition Rocks" (Cambrian), "Submedial or Transition Limestone" (Cambrian), Medial or Carboniferous Rocks," and the "Supermedial or Secondary Rocks." The members of the later official survey showed that De la Beche's age determinations were erroneous, and the rocks were of Cretaceous and Eocene age. These writers gave no satisfactory statement of the subdivisions, which were described in a conflicting manner,[3] chiefly as the "Metamorphosed Series," "Black Shale,"

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[1] Wall and Duncan, Quart. Jour. Geol. Soc. London, Vol. XXI., 1865.

[2] Mem. Trans. Geol. Soc. London, No. 36, 1826, pp. 151-169.

[3] The following names, many of them no doubt synonyms, are used in the Jamaican Report for beds included in our Blue Mountain Series: —

Lower Tertiary or Conglomerate Series; the Trappean Series; sandstone and gravel; upper sandstone clays and shales; black shale; Carbonaceous shales; sandstone formation; conglomerate.

Upper conglomerate; upper conglomerate series; lower conglomerate, etc.

Purple shale and conglomerate; purple shale and conglomerate formation.

Cretaceous group; Cretaceous limestone; Cretaceous series; Cretaceous and Hippurite limestone.

Metamorphosed Series; Metamorphosed or altered rocks; Metamorphosed Series and igneous dikes; Metamorphosed conglomerate; Altered stratified and igneous rocks; Altered Stratified Series.

Igneous formation; igneous rocks; porphyritic dikes, granite rocks, syenite, granite, and syenite of Tertiary age.

"Trappean Series," "Cretaceous Limestone," and "Yellow Limestone" (as used for the western parishes).

While it is still impossible completely to differentiate all the beds of the Blue Mountain Series, our observations have enabled us to make a more accurate classification of them than any hitherto presented, which may be stated as follows: —

Blue Mountain Series	Upper Division (Eocene)	Richmond Beds.	
	Lower Division (Upper Cretaceous)	Minho	Beds.
		Ballard	"
		Logie Green	"
		Frankenfield	"
		Jerusalem	"
		Yallahs	"

The Basement Beds. — The chief difficulty of classification is the complex folding and partial concealment which make it impossible to determine the exact base of the series. The Jamaican Reports present conflicting conclusions on this subject, inconsistently stating in different places that the base of the section is composed of igneous rocks, Cretaceous limestones, and a formation termed the "Metamorphosed Series."

From the tabulations, especially that given on the last page of the Reports, one infers that its authors believed the base of the Jamaican section was crystalline and overlain by the so called "Metamorphosed Series" beneath the limestones with Cretaceous fossils, but a careful perusal of the Reports does not justify this interpretation. In numerous places throughout the text of the work the intrusive nature of the igneous rocks into the beds of the Blue Mountain Series is noted, as further recorded in the portion of our report treating of the igneous rocks. Sawkins[1] expresses doubt as to the propriety of drawing a distinction between the Cretaceous and the so called "Metamorphosed Series," and clearly states that the latter "comprises strata of the Cretaceous and conglomerate formations which have experienced a change of structure due to the intrusion of igneous rocks."[2] In view of this fact, as verified by our own observations, the so called "Metamorphosed Series," as a structural formation, may be dismissed from consideration.

There may be doubt as to whether the oldest rocks are Cretaceous limestone, which Etheridge asserts[3] "is clearly at the base of the series," or "made up of conglomerates" as he states in another place.[1] Duncan and Wall,[2] whose opinions were based on the field observations of Wall, state that "It is difficult or impossible to determine the relation of the conglomerate and Cretaceous groups. This is especially the case in the highly mountainous eastern parts of Jamaica, where traces of almost obliterated Hippurites [Rudistes] and other fossils are detected in strata which from their confined position could not otherwise be classified stratigraphically." They state that in Clarendon, however, "the lowest members of the Cretaceous Series frequently consist of a thin bed of conglomerate formed of the harder material of the porphyries."

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[1] Jamaican Reports, p. 55.

[2] Ibid., p. 47.

[3] Ibid., p. 808.

Barrett said[3] that it is "evident that the igneous rocks forming the base of this series, and interstratified with some of the shales and conglomerates, were erupted prior to the deposition of the Cretaceous limestone, and at intervals of time sufficient for the formation of aqueous interbedded strata."

The writer in his own investigations and in the literature of the island has found no proofs that the base of the section is limestone. The limestones of the Bath and Clarendon sections are clearly intercalations in vast beds of igneous débris. The limestones are certainly the oldest rocks paleontologically identifiable, but from the data to be given the writer believes the fossiliferous Cretaceous beds are local occurrences in the great and tangled series of tuffs and conglomerates, the latter of which constitute the visible base of the section. These are detrital formations of volcanic débris of unknown origin. The writer searched the exposures with particular care, but in vain, for evidence of some older or lower lying rocks beneath the classic formations of the Blue Mountain Series such as are reported in Cuba and Haiti, or a trace of ancient massifs or volcanic vents from which the detrital igneous rocks were derived.

The Clarendon Section. — The best partial section of the lower division of the series is in the parish of Clarendon, along the St. Thomas and Minho Rivers, where all the beds, not including the lowest and highest of the series, are exposed in a less disturbed condition than elsewhere. This parish was considered by Sawkins[4] and Wall and Duncan[5] to afford the most complete exposition of the relationship of the older beds to be found in Jamaica. In order to verify these previous observations, the writer reviewed this section *de novo* and made the following record, which adds many new data. This section also shows the mode of occurrence of the fossiliferous Cretaceous rocks. Many of the Rudistes recently described by Whitfield came from this section.[1]

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[1] Jamaican Reports, p. 307.

[2] Quart. Jour. Geol. Soc. London, 1865, Vol. XXI. p. 3.

[3] Quart. Jour. Geol. Soc. London, 1860, Vol. XVI. pp. 324–326.

[4] Jamaican Reports, p. 25.

[5] Quart. Jour. Geol. Soc. London, Vol. XXI. p. 4.

CLARENDON SECTION, RIO MINHO, CLARENDON PARISH.

14. Cambridge Beds, Chapelton Formation. — Yellow Marls and limestones (further described under the head of Cambridge beds) with Eocene fossils. Exposed between the town of Clarendon and St. Thomas River . . . . +500 ft.

13. Unconformity. Richmond Beds wanting.

12. Minho Beds. — Volcanic tuffs and breccias, composed of igneous pebble (hornblende-andesites) cemented by a fine-grained matrix. Groundmass ashen or dark green in color. Exposed in the banks of St. Thomas River west of the ford and the divide between the St. Thomas and Minho, and between Mile Posts 38 and 39. Estimated thickness . . . . +300 ft.

11. Impure granular semi-consolidated material of dark red color, with same pebble as above. This is largely an andesite tuff showing many particles of hornblende. This constitutes the faces of many fine bluffs between Mile Posts 39 and 40. Its base in contact with the foregoing is well shown at the crossing of the Minho. Estimated thickness . . . . +300 ft.

10. Stratified conglomerate of igneous pebble in red matrix becoming black downward.

9. Massive tuff or igneous rock . . . . 200 ft.

8. Chocolate-red colored breccia . . . . ± 50 ft.

7. Stratified (tuff?) conglomerate rounded black igneous pebble in indurated mass.

6. Ballard Clays. — Black, bituminous, laminated clays, sienna colored above, resembling in color the Richmond beds, with occasional yellow calcareous interbedded layers, containing small colonies of Rudistes. This is finely exposed between Mile Posts 40 and 41, the descent of Ballard Hill towards Ballard River, where over 150 feet are seen . . . . ±200 ft.

5. Tuffs.

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[1] Bull. Am. Mus. Nat. Hist., Vol. IX., Article XII., New York, 1897, pp. 185–196.

4. Logie Green Beds. — Yellow clays, similar to those at Pennant's Great House on the St. Thomas, containing fossil Rudistes. Exposed at base of above section. Thickness of these clays indeterminate. They are exposed intermittently as far as Trout Hall, and Mile Post 44 . . . . +100 ft.

3. Frankenfield Beds. — Beds twenty feet in thickness of large igneous cobble stone of hornblende-andesite embedded in an ashen gray matrix of tuff, grading down into, or possibly unconformable upon, a great thickness of tuff without conspicuous pebbles. This formation is exposed in superb cuts on both sides of Frankenfield between Mile Posts 44–49. Towards Logie Green there are boulders of porphyry, becoming smaller above. These beds may be from 500 to 1,000 feet thick. Three hundred feet are exposed in the high hills back of Trout Hall . . . . +500 ft.

2. Limestone Beds. — Great masses of hard blue-white limestone over 20 feet thick, with gigantic Rudistes, Actæonella, and corals. Apparently bosses in the igneous conglomerate and tuffs.

1. Yallahs Formation. — Conglomerate of porphyritic boulders. Base concealed. This is the bottom of the section of the Blue Mountain Series, as seen in Clarendon Parish.

All the beds of the foregoing section have a very strong south dip of ±30° beneath the white limestones on the south of the Clarendon basin.

This section does not agree with that given by Duncan and Wall, as previously cited, in which the divide of the St. Thomas and Minho (Long Ridge) is represented as a hill of massive igneous rock protruding through and disturbing the sedimentaries. On the contrary, this hill is composed of stratified tuff.

The Clarendon section, although the best exposed on the island, does not represent the Blue Mountain Series in its entirety, nor are its facies everywhere uniform or continuous. Rocks similar to these compose the material of all the higher mountains of the eastern half of the island, but there they occur in such a disturbed condition that the members cannot be easily differentiated. A greater thickness of the lower conglomerates is exposed in the Blue Mountain districts. The hiatus in the Clarendon section between the top of the Minho beds and the Cambridge is elsewhere represented by the formation to be described as the Richmond beds as best seen on the north side of the island. Collectively the beds of the Clarendon section constitute the lower subdivision of the Blue Mountain Series, and with all its variations is quite different from the Richmond beds of the upper division.

In general, the Minho beds correspond in character with the "Trappean Series and Purple Shales and Conglomerate Formation" of the Jamaican Reports, occurring extensively from Clarendon eastward to Bath in St. Thomas, and notably near Gordontown, back of Kingston, in the ribbed salients (cuchillas) of Newcastle, and in Metcalfe. These beds are marked by great abundance of gravel and tuffs and purplish colors. They are placed in our section below the black shales and conglomerates of the Richmond beds, not above, as in the final tabulation of the Jamaican Reports.

The Fossiliferous Beds of the Lower Division of the Blue Mountain Series. — The massive limestones occur lower in the series in more or less isolated and widely separated outcrops, nowhere of great thickness, and characterized by the Rudistean fossils.

The Jamaican Reports treat of the fossiliferous Cretaceous beds included in the series as a single formation. It was described [1] as composed of two varieties of strata constituting an upper and lower part. The former was said to consist of marls and sands with corals and many Hippurites, the latter of compact massive limestones with many Radiolites and Barrettia. These statements are misleading. It is true that the oldest fossiliferous Cretaceous rocks exposed are limestones, and that the marly beds with Cretaceous fossils, of which there are several horizons instead of one, occur higher than the limestones; but these beds are merely incidents in the great series of volcanic tuffs and conglomerates with which they are interbedded, as is seen in the details of the Clarendon section. No. 2 of the Clarendon section with Cretaceous fossils is the lowest limestone. These are overlain by the Frankenfield tuffs. Above the latter appear fossiliferous beds of the Logie Green,[2] and Ballard clays which in turn are covered by the Minho tuffs.

The Cretaceous limestones are found in several other places on the island. Sometimes a limited mass occurs in a manner to create doubt as to whether it is a bed, a local lens, or a great transported boulder;

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[1] Jamaican Reports, p. 26.

[2] Local beds of yellow marl and impure segregated limestone are also exposed near Trout Hall on the Minho, and at Pennant's Great House on the St. Thomas, and consist of a considerable thickness of the unctuous yellow clays and segregated limestone lumps with numerous specimens of smaller Rudistes (including many of the species described by Whitfield) and corals.

again, as in the canyon of Plantain Garden River in Portland, where the Cretaceous rocks of Jamaica were first noted by Barrett,[1] a single stratum of limestone is interbedded between overlying and underlying tuffs, conglomerates, and clays. Sawkins noted in southwest Portland "thin beds of Cretaceous limestone, interstratified with thick porphyritic breccias and conglomerates, enclosing contemporaneous trap rocks."[2]

The writer tried to visit all the localities mentioned, three of which, Clarendon, Jerusalem Mountain, Westmoreland Parish, and Bath, in St. Thomas, may be taken as typical. These are in the central, western, and eastern portion of the island respectively.[1]

Jerusalem Mountain Section. — In at least one locality Cretaceous limestones occur in extensive beds. This is near the extreme west end of the island at Jerusalem Mountain in the parish of Westmoreland. This was probably sufficiently remote from the centres of igneous activity to permit undisturbed oceanic conditions and continuous growth of life. Jerusalem Mountain is a low, isolated hill standing 570 feet above the sea and about 500 feet above the surrounding valley plains. It is composed entirely of Cretaceous limestones and dull yellow clays, except at its eastern base, where the Tertiary limestones rest unconformably against it, probably by faulting. The rocks dip slightly to the east. Here we made the following section: —

Later Formations at Foot of the Hill.

		Feet.
IV.	Yellow shale resembling Richmond beds, with beds of limestone; weathers into purple colors	25
III.	Minho Beds. Purple clays and blotched shales dipping east	60
II.	"White limestone" in bluish shale, fossils Tertiary?	50
I.	Level of valley plain of Mount Eagle. Alluvium	60

Section of the Hill.

VI. 14.	Summit of brown marls with Alectryonate oyster in thin limestone slabs, Pholadomya, etc.	25
V. 13.	Yellowish limestone with small fossils	15
12.	Red purple clay	10
11.	Dimension layers one foot thick, of impure limestone with Alectryonate oyster	10
10.	Yellow marl	22
9.	White fossiliferous limestone, Caprinella	20

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[1] Quart. Jour. Geol. Soc. London, Vol. XVI. pp. 324–326.

[2] Jamaican Reports, p. 74.

		Feet.
8.	White limestone with Actæonella	40
7.	White limestone slightly yellowish	25
6.	Yellow marl alternating with limestone	50
5.	Purple shale in yellow limestone and marl	15
4.	Red "Trappean" conglomerate	6
3.	Yellow marls with limestone lumps and gigantic Caprinas	29
2.	Three feet layer of limestone with giant Caprinas	67
1.	Yellow clays and limestones	23

Nos. I., II., III., and IV. of the foregoing sections are undoubtedly of later age than V., and owe their present lower topographic position to faulting or later unconformable deposition. It is interesting to note that the gigantic species of Rudistes occurs at the base of this section in bed V. 2, — a low position apparently persistently maintained throughout the island.

It is unfortunate that here the relations of the fossiliferous formations to the other beds of the Blue Mountain Series are concealed.

It might be supposed that the yellow clays at the top of the Jerusalem section represent the horizon of similar material elsewhere widely separated from the lower limestones by vast beds of tuffs and igneous conglomerates. The paleontologic data do not demonstrate this conclusion, the fossils of the Jerusalem clay beds (Pholadomya and Ostræa) not being found at other localities, nor are some of the smaller species of Rudistes of probably higher horizons found here. Outcrops of "Cretaceous limestone" 500 feet thick in St. Thomas-in-the-Vale,[1] and 300 feet thick in Port Royal,[2] are also recorded, but the writer has not seen them.

It is barely possible that a locality in Portland, mentioned by Barrett,[3] may represent the upper clay horizon. This was described as "a sandstone conformable with a thick bed of clay containing Hamites, Baculites, Trigonia, and Pholadomya." This reference is the only mention of the first three fossils from Jamaica.

Near Bath, at the eastern end of the island, Cretaceous limestones are exposed in the elevated structure near the southern base of the mountains. This is the locality from which the Cretaceous of Jamaica was first described by Barrett, who published a figure of the section.[4] The principal formation of this vicinity is the Minho beds (Trappean of

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[1] The Cretaceous of St. James, as described by Sawkins (Jamaican Reports, p. 245) is the Cambridge formation of this paper.

[2] Jamaican Reports, p. 138. [3] Ibid., p. 62. [4] Ibid., p. 77.

Sawkins), here composed of volcanic tuff with conchoidal fracture and weathering into rusty red clays, metamorphosed shale, and occasional pieces of contained impure limestone. About a mile up the Plantain Garden River the stream has a steep V-shaped canyon surrounded by hills. A new highway which is being constructed shows fine cuts of the prevalent Minho formation. In this we found exposures of hard strata of Cretaceous limestone, aggregating several feet in thickness, but the vegetation was so thick that the latter fact could not be determined positively.

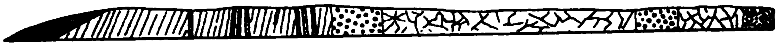

FIGURE 15. Barrett's Section, near Bath.

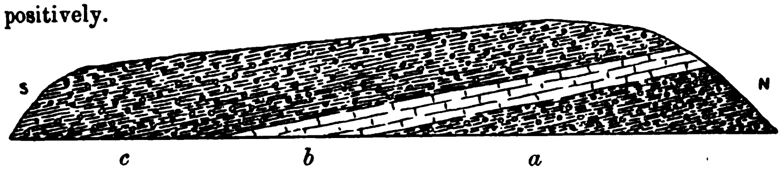

FIGURE 16. Plantain Garden River Section at Bath. *c*. Trappean Material above. *b*. Cretaceous Limestone. *a*. Trappean Material below *b*.

Below the limestone (*b*) are *altered shales* and decomposed volcanic conglomerates, some of which weather into dark colored chocolate or vermilion colors.

In nearly all the localities of the Jamaican Survey, with the exception of the Jerusalem exposure, the limestones have the appearance of localized beds in the midst of the general material of the Blue Mountain Series,[1] and not of widely extending or persistent strata.

These beds occupy no persistent horizon but occur at various intervals in the great aggregation of deposits. Our observations incline us to agree with Sawkins,[2] that "it would appear from the occurrence of the limestone in detached places that it originally formed isolated reefs."

The marls succeed the bedded limestones in ascending series, and vary from 50 feet to an inch in thickness as seen in the clays along the Minho, at Ballard's above Clarendon, at Pennant's Great House, and Trout Hall. In general, these clays contain fossils which represent intermittent life colonies which have found temporary habitation in periods of quiescence during the irregular deposition marking the formation of the earlier part of the Blue Mountain Series.

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[1] Barrett, Quart. Jour. Geol. Soc. London, 1860, Vol. XVI. pp. 325, 326.

[2] The Metamorphosed Series, Trappean Series, Black Shale, and Conglomerate of Sawkins.

From the data presented, with the exception of the Jerusalem section, and the observations of other writers, it is evident that the limestones and marls containing the Cretaceous faunas occur interbedded with the conglomerates, tuffs, and shales of the lower portion of the Blue Mountain Series, and become less and less conspicuous in ascending sequence.

Sawkins[1] has spoken of the limestones as "being disposed in a zone around the higher elevations," and as "forming a zone around the great nucleus of upheaval of the island."[2] If this were correct, it might be possible that much of the Blue Mountain Series is antecedent to these beds. This statement is not accurate, however, for these limestones are found not only around but folded in the plexus of beds constituting the highest mountains, occurring on Blue Mountain Peak as high as Abbey Green, 4,200 feet above the sea. Even if true, the statement would be applicable only to the eastern end of the island, for all exposures of these beds west of the longitude of Spanish Town (except Jerusalem) are in the central basins where erosion has cut down to them through the overlying White Limestones and Blue Mountain Series. This is especially so at Clarendon, where the beds are covered by hundreds of feet of the same rocks which constitute the high summits of the east.

The tuffs, igneous pebble, and boulders of the lower subdivision are composed almost entirely of hornblendic material, — andesites and porphyries, — which shows that this was the chief eruptive material of Jamaica during this epoch, and of which the Minho beds apparently represent the débris of the last expiring extrusion. These indurated tuffs often have a superficial resemblance to altered clays and sandstones, and this aspect, in addition to undoubted occasional igneous metamorphism, was the reason why the beds were in places called the "Metamorphosed Series."

All beds of the lower subdivision, taken collectively, represent the product of disturbed conditions, such as active vulcanism accompanied by the piling up and contemporaneous degradation of vast quantities of igneous material much of which was deposited below sea level, alternating with short periods of quiescence, when shales and marls were permitted to accumulate and sparse faunas to gain temporary foothold. The alternations of shale and igneous material in the Blue Mountain Series indicate alternating conditions of sedimental placidity and volcanic extrusion, and a conflict between disturbed and quiescent conditions of deposition which finally culminated in the establishment of the latter in the succeeding Richmond epoch.

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[1] Jamaican Reports, p. 105.

[2] Ibid., p. 22.

THE RICHMOND BEDS.

These beds constitute the upper subdivision of the Blue Mountain Series. Their arrangement and composition, consisting of shallow marine deposits of worked over and water assorted terrigenous material, indicate a succession of more quiet sedimental conditions than those which marked the preceding epoch.

The rocks are mostly black, bituminous, laminated clays, and ferruginous sandstones with occasional beds of loose conglomerate. They occur in uniform alternations of thin, regular, and evenly bedded strata, varying from an inch to a foot or more in thickness. They are dull blue-black on fresh exposure, but undergo excessive oxidation and hence are ordinarily of dark brown ferruginous colors. In general texture, arrangement, color, and stratification they resemble the Eo-Lignitic (Lower Eocene) beds of the southern United States. The clays contain many small flakes of carbonized vegetal matter, and silicified wood has been found in the gravel. The material is mostly derived from the antecedent beds of the lower division of the Blue Mountain Series. The so called "sandstones" are composed of cemented grains of water worn hornblende-andesite derived from the underlying igneous rocks, and the shales are the same material more finely triturated and mixed with vegetal matter. The conglomerates consist of rounded pebbles of various dimensions, and in places attain a thickness of 50 feet. They are almost entirely of the same material as those of the lower subdivision. Rounded fragments of the Rudistean limestone also occur in them. These have been noted first by Barrett,[1] then by Sawkins and others of the Jamaican Survey, in the parishes and districts of Portland, St. James,[2] St. George and Metcalfe, St. Mary, and St. Thomas-in-the-Vale. In addition to these rocks of the conglomerate, former observers have noted,[3] from the bluff at Port Maria, specimens of gneiss and crystalline slates, "rocks of which no trace either *in situ* or otherwise have hitherto been found in Jamaica; also a fine-grained granite to which nothing analogous has been noted on the island. . . . In this unique collection are many instances of rocks which have totally disappeared from the surface of Jamaica, but which must have existed during former epochs, either in the formations of this country or in adjacent lands that have been destroyed."

At the same locality, as also noted in the Jamaican Reports,[4] the ordinary sandstone is rapidly transformed in its seaward extension into a promiscuous assemblage of large pebbles six or eight inches in diameter. This fact indicates that some of this material came from the area to the north, now occupied by the sea. In this same bed of conglomerate were found the Eocene corals described by Duncan, and a few species of mollusks. An excellent view of this exposure of conglomerate at Port Maria is given on Plate XXIII. The character of its beds as shown in Figure 17 is as follows: —

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[1] Quart. Jour. Geol. Soc. London, 1860, Vol. XVI. pp. 324–326.

[2] Jamaican Reports, pp. 245, 246. [3] Ibid., p. 130. [4] Ibid., p. 130.

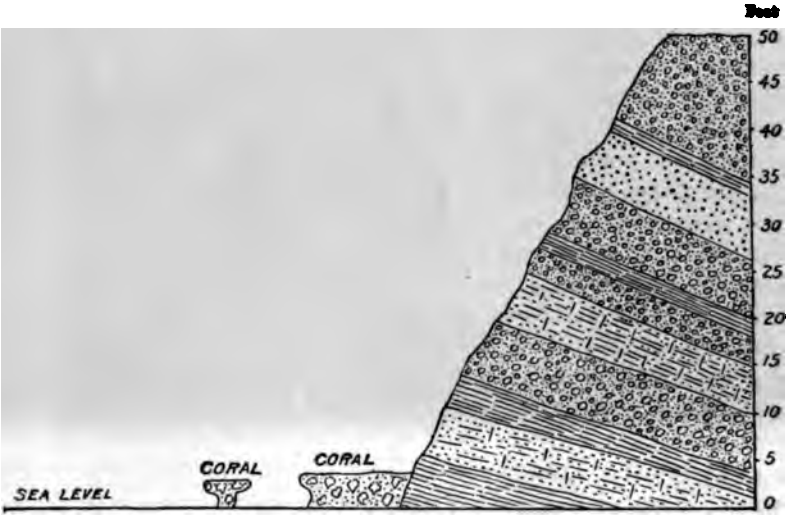

FIGURE 17. Section of Richmond Beds at Galinas Point. Section of Bluff West Side of Harbor at Port Maria.

	Feet.
Conglomerate	15
Shaly sandstone	3
Sandstone	10
Conglomerate	10
Shaly arenaceous clay	3
Conglomerate	5
Bluish rock, probably sandstone	10
Conglomerate	15
Shaly arenaceous clay	5
Bluish rock	11
Shale	+10
	+97

The Richmond formation is exposed in all parishes of the east adjacent to the Blue Mountain Ridge, but in a greatly disturbed condition. It is best seen in the north coast parishes of Portland, especially the districts of St. George and Metcalfe in St. Mary Parish; and in Hanover, in the bluffs and hills of the back coast country, east, west, and south of Lucea. Excellent and typical exposures are seen between Richmond, district of Metcalfe, St. Mary Parish, and Annatto Bay, the beds occurring in many short open anticlinal and synclinal folds. At Richmond a bluff in the banks of Flint River well shows the thin alternations of evenly bedded shales and sandstones overlying the conglomerates. (See Figure 18.)

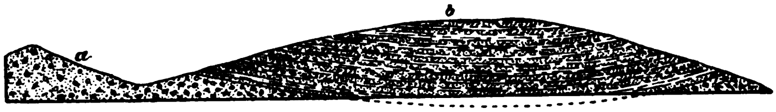

FIGURE 18. Section showing Richmond Beds at Richmond. *a*, Conglomerate grading into *b*, alternations of Conglomerates and Clays.

At Moral Cut, near Moral Station, thin flags of impure arenaceous limestone appear in alternation with the beds of shale (Fig. 19), and weather out in great quantities. This exposure is part of an openly folded anticline, over a mile in length, consisting of rusty brown gravel below, and shales, limestones, and sandstones above. In the west bank of Wag Water the Richmond beds are vertical. Many other excellent exposures occur in this portion of the parish of St. Mary, constituting the western terminus of a belt of the formation which extends thence in a south of east direction through Portland Parish. It is impossible to obtain continuous sections of these beds, owing to minute folding and concealment of contacts by vegetation and overlapping formations.

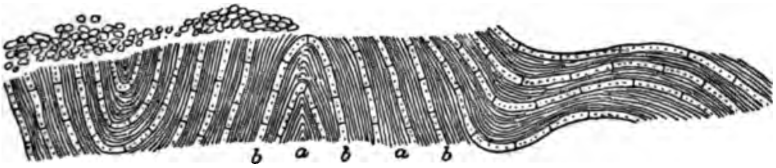

FIGURE 19. Folded Richmond Beds, St. Mary Parish. (From the Jamaican Reports.)

The Richmond beds of this district succeed without break the Minho formation (Purple Shale and Conglomerate Formation of Wall), which are described[1] as "great masses of green and red argillaceous strata and apparently belonging to a lower division of the group."

Wall[2] gives under the name of the "Black Shale" the following section of the Richmond beds in St. George and Metcalfe.

	Feet.
Red and light yellowish shale	±100
Thin alternations of grayish sandstone and shale weathering brown	±300
Brownish green shale, finely laminated, black color, containing alternations of thin sandstones, rubbly conglomerate, and pieces of Cretaceous limestone and fossil Hippurites and Caprinella much water worn	±1,000
Purple shales finely laminated passing into metamorphosed conglomerate and shale (Minho beds).	

This section makes no mention of the upper beds containing limestones, which, in our opinion, represent a gradation into the overlying Cambridge formation.

In the northern part of Hanover Parish the Richmond beds have considerable development, and, so far as composition is concerned, present the same general facies previously mentioned. In this parish they are exposed in the back coast bluffs from the mouth of Great River westward, being capped above by the White limestones of the Oceanic Series, and in their seaward extension cut into many terraces, upon some of which are plastered old coral reefs like that shown near Barbican, in Figures 33 to 36. Superb exposures are seen around the interior end of Lucea Harbor and in the uplands to the south half way across the island along the road leading toward Savanna-la-Mar. In this region the beds are intensely folded, faulted, and overthrown, as shown in the view on Plate XXII. It is our opinion that nothing less than months of minute study of the complicated folds of this region would reveal the detailed sequence of the individual members of the beds in this parish. The following section may be inferred[3] from descriptions of Brown and Sawkins. The formation names are ours.

Richmond Beds.

	Feet.
Thin laminated beds of red, gray, and greenish shale	±200
Beds of pebbly conglomerate, overlying beds of massive brownish and gray sandstone	300
Greenish brown laminated shale, interstratified with thin beds of fine-grained sandstone	+2000

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[1] Jamaican Reports, p. 68.

[2] Ibid., pp. 121, 122.

[3] Ibid., pp. 252, 253 ("Black Shale").

Minho Beds.

Metamorphosed conglomerate "of subsequent date to that of the Cretaceous limestone," composed of "various crystalline rocks embedded firmly in a hard crystalline base; the whole is of a greenish color" (Tuff?).

The Richmond formation outcrops in many places a short distance back of the sea along the north coasts of the parishes of St. Ann and Trelawney. It is well exposed beneath the Cambridge beds south of Cambridge along the highway on the west side of Great River, as seen by the writer. It also occurs on the south side of the Blue Mountain Ridge in St. Andrews and St. Thomas. According to Sawkins,[1] in the latter parish at Blue Mountain Valley it consists of "alternate bands of red clay, yellow sandstone and light gray shales, 1,000 to 1,200 feet in thickness."

In general, this formation underlies nearly all the later rocks, and, in our opinion, prior to the Montpelier subsidence it occupied an area as large or larger than that of the island of to-day.

From data presented in the paleontological chapter of this work, the age of these beds is undoubtedly old Eocene, although it is impossible to draw an exact line between these beds and those of the lower division which we have termed Cretaceous, and they are no doubt stratigraphically continuous.

The uniform alternations of the Richmond beds indicate that they were rapidly deposited over a considerable shallow area of deposition; since much of this area was the present locus of the island, it is difficult to infer the situation of the near-by land from which the material was derived; some of it may have come from the old nucleus of Blue Mountain Ridge, but in our opinion this was not of sufficient size to afford all the material. These facts, together with the presence of foreign material, are at least strongly suggestive of the occurrence of land areas during this epoch, concerning the locality of which present knowledge is wholly wanting.

THE CAMBRIDGE FORMATION.

The beds are named after the typical locality of their occurrence at Cambridge, between Ipswich and Montpelier, in the parish of St. James, in the northwestern portion of the island, near the junction of the boundaries of St. James, Hanover, and Westmoreland.

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[1] Jamaican Reports, p. 105.

In places the Richmond beds grade up into irregular alternations of impure clay, marls, and yellow limestones, which, in general, occupy a transitional position between the obviously land derived beds of the Blue Mountain Series and the ocean derived limestones of the Oceanic Series. Argillaceous calcareous marls appear in the upper part of the Richmond beds, become successively more and more frequent, and finally dominate. These are accompanied by thin beds of impure blue limestone of a segregational character, oxidizing yellow on weathering and alternating with the marls which gradually increase in thickness and relative proportion until they preponderate. Finally, these yellow limestones become more purely calcareous in ascending series as the sediments become clearer and freer from land derived material, until they finally pass into the purer White limestones.

This formation has limited exposures at many places in the island, notably around the lower margins of the interior basins in Trelawney, Westmoreland, and Clarendon, and in the eastern parishes, as mentioned later. We shall first describe their occurrence in two typical localities at Catadupa near Cambridge, and at Chapelton, Clarendon Parish, respectively. Owing to certain differences which at present do not permit of perfect correlation, these will be respectively termed the Catadupa and Chapelton beds of the Cambridge Formation.

The Catadupa Beds.

They are well exposed on the east margin of Great River valley, in the new cuttings along the Montego Bay Railroad between Ipswich and Montpelier stations, and especially between points two or three miles south of Catadupa and one mile north of Cambridge. Here the railway cuttings reveal splendid exposures, and afford good places for collecting fossils and studying the stratigraphy. These beds occur in a series of short open folds, as shown in Figure 20.

These folds are all less than two hundred yards in length, but the continuity of the beds is so broken that their exact sequence and thickness can be made out only with difficulty. Here the beds consist of alternations of massive and friable strata of yellow blue limestone, one to three feet in thickness, separated by thin bands of blue-black shale containing oysters, large Cerithii, Lucina, Rudistes, Carolia, Triloculina, etc.

A general geological section of the east slope of the valley of Great River, between Cambridge and Catadupa, showing the relations of the formation, is as follows.

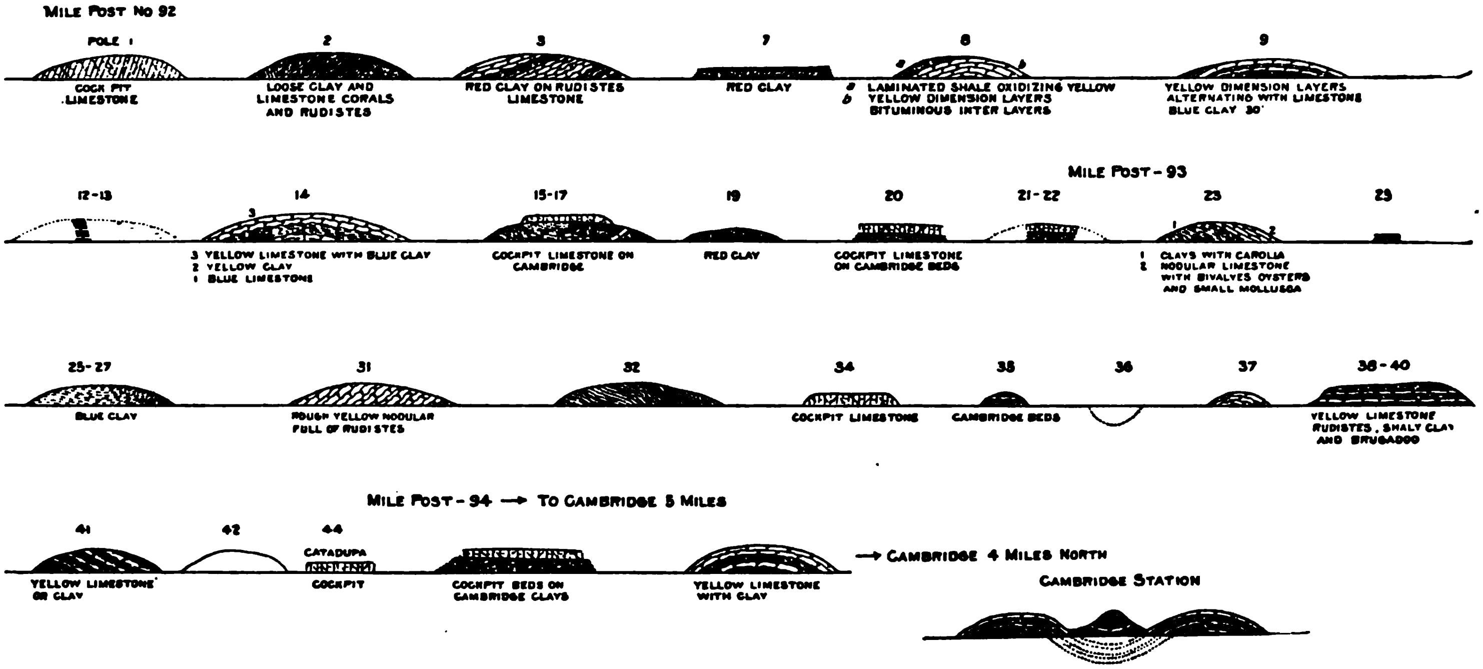
MILE POST No 92
POLE 1
COCK PIT LIMESTONE
2
LOOSE CLAY AND LIMESTONE CORALS AND RUDISTES
3
RED CLAY ON RUDISTES LIMESTONE
7
RED CLAY
8
a
b
a LAMINATED SHALE OXIDIZING YELLOW
b YELLOW DIMENSION LAYERS BITUMINOUS INTER LAYERS
9
YELLOW DIMENSION LAYERS ALTERNATING WITH LIMESTONE BLUE CLAY 30'
MILE POST - 93
12-13
14
3
2
3 YELLOW LIMESTONE WITH BLUE CLAY
2 YELLOW CLAY
1 BLUE LIMESTONE
15-17
COCKPIT LIMESTONE ON CAMBRIDGE
19
RED CLAY
20
COCKPIT LIMESTONE ON CAMBRIDGE BEDS
21-22
23
1
2
1 CLAYS WITH CAROLIA
2 NODULAR LIMESTONE WITH BIVALVES OYSTERS AND SMALL MOLLUSCA
23
25-27
BLUE CLAY
31
ROUGH YELLOW NODULAR FULL OF RUDISTES
32
34
COCKPIT LIMESTONE
35
CAMBRIDGE BEDS
36
37
38-40
YELLOW LIMESTONE RUDISTES, SHALY CLAY AND BRUGADOO
MILE POST - 94 → TO CAMBRIDGE 5 MILES
41
YELLOW LIMESTONE OR CLAY
42
44
CATADUPA
COCKPIT
COCKPIT BEDS ON CAMBRIDGE CLAYS
YELLOW LIMESTONE WITH CLAY
→ CAMBRIDGE 4 MILES NORTH
CAMBRIDGE STATION

Figure 20. Exposure of Cambridge Formation near Catadupa and Cambridge.

Montpelier Beds.

	Feet.
Homogeneous textured white chalky limestone with flints, resting unconformably upon the Cambridge beds	+500

Cambridge Beds.

Yellow colored granular limestones (blue before oxidation) alternating with clays, with many fossils	±100
Blue, black, and purple clays grading into above	±100

Richmond Beds.

Blue and black clays without calcareous beds grading down into thin alternating beds of clay and sandstone	±25
Purple colored clays, without regular lamination	±25
Slightly calcareous beds in above	±25
Purple and blue-black arenaceous clays, extending down to bed of Great River	+200

The clays and marls are black and unctuous in some places; in others they are yellow, excessively calcareous, and full of minute Foraminifera (Miliolidæ), and grade from black into blue and gray colors upon drying, and into yellow on oxidation. The Foraminifera are so abundant that they give an oölitic look to some of the rocks, but on oxidation they crumble into small specks of pulverulent lime. This lime, after solution and redeposition, largely makes the segregations of limestone. Sometimes the clay seams are so bituminous they have the appearance of thin lignitic beds.

The limestones occur in layers of various thickness up to two feet; they are nodular and irregular both in thickness and texture. At some places they are firmly indurated, at others they are friable and shaly. They are clearly chemical and clastic segregations in the great mass of clays, and gradually increase in proportion as we ascend in the series, while the clays similarly decrease. In freshly exposed portions the limestones are also blue-black in color. On weathering they become bright yellow, as a result of the oxidation of small amounts of iron which accompany the fossil colonies.

Many fossils — Echinoderms, Corals, Rudistes, and other Mollusca — which are listed in another chapter of this report, occur in the calcareous portions of these beds, both as free shells in the clays or making the greater mass of the limestones. Some of the latter in the cuts south of Catadupa are almost entirely composed of Rudistes, which also occur more sparingly in the beds at Cambridge. Oysters and

Mollusca are most abundant in the "Bruggadoo," as the black clays at the railway cut where so much slipping has occurred are called.

Chapelton Beds.

In Clarendon Parish, at Chapelton, and in the slopes of the Minho River east of that town, beds allied to the Cambridge formation are exposed. These present two subdivisions, the upper of which consists of more or less massive beds of yellow foraminiferal (Orbitoidal) marl alternating with bedded yellow limestones and grading up into the white Montpelier limestones; the other is mostly composed of creeping blue, black, and red clays known in Jamaica as "Bruggadoo," resembling similar material of the Catadupa section, and in which occasional fossiliferous calcareous layers only an inch in thickness and a few yards in length are exposed.

The higher subdivision has its typical occurrence along the main street of the village of Chapelton, between Chapelton Hill and the River St. Thomas. The second is exposed along the "lower" road which parallels the foregoing street but follows a lower contour in the valley of the Minho. The following local section of this subdivision was observed at Chapelton, between the hill in Chapelton upon which the residence of the Inspector of Constabulary is situated, and the bed of St. Thomas River two miles north. This section is the upward continuation of the general Clarendon section given on page 46. The thicknesses given are approximated: —

	Feet.
3. Bed of yellow marl and thin limestone alternating, containing Orbitoides and small Ostrea, estimated thickness	185
2. Blue and purple clay	115
1. Yellow marl, clay, and limestone	75

At Mr. Craig's estate in the river valley a considerable mass of yellow limestone (No. 1) is exposed, but it was impossible to find determinable fossils therein, or to decide the exact position of this mass relative to the clays. It was our impression that it occurred about midway in the general section. Down the valley slope, on the so called lower Chapelton road, which follows the river and cuts into beds lower than those of the above section, many isolated cuts are exposed, composed entirely of the blue and purple clays, with an occasional thin local layer of yellow clay containing crumbling fossil oysters, Carolia, and Foraminifera. From reasons given in the paleontologic discussion, these lower beds are supposed to be equivalent to those of the Catadupa section, and the upper are a higher extension of the same.

In addition to the particular localities of the Cambridge beds mentioned, there are many others throughout the island. Near Mooretown, Mt. Pleasant, and Shrewsbury, Portland Parish, are beds described by Barrett,[1] which correspond closely with them in position, arrangement, and fossiliferous remains.

On the north side of the east end in St. Mary's and Portland parishes the Cambridge beds are much more calcareous than elsewhere, as seen in an exposure at the foot of the bluffs west of Port Antonio, where its characteristic fauna is found in beds of pure white limestone and calcareous marl much resembling the overlying white limestones of the Montpelier formation, into which it here grades without perceptible break. A considerable mass of the white marl at this locality is composed of large granular Foraminifera very like those found in the black shale of the Catadupa locality. This white foraminiferal marl is probably the same as that from near Carron Hall, St. Mary,[2] in which parish, near Guy's Hill, the typical Cambridge fauna is found just below the flint beds of the Montpelier. At this locality the beds have their characteristic variations of color. Near Preston Falls, in the same parish, the lime beds of the formation grade down into the Richmond beds. In this parish Wall estimates the thickness of beds which we place in this formation described by him, together with a part of the overlying white limestones, under the name of the "Calcareous Marl,"[3] to be between 500 and 600 feet.

In the district of St. Thomas-in-the-Vale, parish of St. Catherine, the Cambridge formation, with the typical Chapelton fossils, consists of yellow marl and red and blue colored clays with impure lignite, and is about 300 feet thick. It is well displayed in the hilly district southwest of Guy's Hill.[4] Near Spring Vale, in the same parish (St. Catherine), south of Linstead, at the southern angle of the St. Thomas basin, the Cambridge beds are composed of yellow clays and sand extremely rich in Ostrea and Foraminifera. In the parish of Manchester, the Cambridge beds occur at many places, notably at Spice Grove, Amby, Lower Mayfield, Oxford, Cowie Park, along Hector River and at Christiana. A good description of the beds at these localities is given under the head of "Yellow Limestone" by Brown.[5] The following section of these beds on Hector River is by him: —

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[1] Jamaican Reports, p. 84.

[2] Ibid., p. 129.

[3] Ibid., pp. 129, 130.

[4] Ibid., p. 139. Described under name of "Calcareous Marl."

[5] Ibid., pp. 169–171.

	Feet.
Hard compact yellow limestone, very crystalline; thickness about	10
Soft yellowish shaly limestone	5
Soft shaly yellowish limestone, showing peculiar strained concretionary nodules in one part of the bed	2½
Yellowish limestone, hard and coarse	2
Yellow marl	
	+19½

It is an interesting fact that Brown considered the yellow limestone beds of Christiana, from which Mr. F. C. Nichols later collected several of the Rudistes recently described by Professor Whitfield,[1] to be of Eocene age. This strongly suggests that future study of the locality may reveal a mixture of Cretaceous and Eocene genera like that occurring at Catadupa.

The Cambridge beds, with their characteristic fossils, especially the oyster and large Cerithium, outcrop at many places in St. Ann, notably at Cave Valley, Boroughbridge, Yankee River, Pedro estate, and in the beds of Negro and St. Ann Rivers. They have also been noted in Trelawney at several places, and beds of Orbitoidal limestone with other fossils are well exposed near Freeman's. The outcrops of the Cambridge in Westmoreland and Hanover parishes are all in the same general district as those of Catadupa and Cambridge in St. James, — the three parishes meeting in this vicinity. The thickness is from 40 to 300 feet.

The identity of this formation is involved in Jamaican literature. In places it is clearly defined and in others its identity is entirely lost. In De la Beche's chapter on the "White Limestone" of Jamaica,[2] many descriptions of these beds and their fauna can be recognized. It is also the "Nodular Limestone" of Barrett's posthumous section published by Woodward,[3] and mentioned in our introductory chapter.

In the Jamaican Reports it is the "Yellow Limestone" of Sawkins's general section on page 24, and of the western parishes of St. Elizabeth, St. James, Hanover, and Westmoreland, as described by Brown, who considered the formation to be Eocene. In the descriptions of the remaining parishes it has been so confused under many names with other beds of different age and position that its identification is somewhat difficult, although by careful study of the reports uncorrelated descriptions of its parts are occasionally recognized. In reports on the other parishes it has been termed "White Limestone," and "Calcareous Marl" of St. Thomas-in-the-Vale, Metcalfe, and St. Mary, and referred to the Cretaceous, Eocene, and Miocene ages.

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[1] Bull. Am. Mus. Nat. Hist., New York, 1897, Vol. IX. pp. 185–196.

[2] Jamaican Reports, pp. 169–182.

[3] The Geological Magazine of 1864.

The term "Yellow Limestone" is peculiarly applicable to these beds, but unfortunately this name was also applied, through the erroneous correlation of Wall,[1] Etheridge,[2] and others, to the beds of Oligocene age at Bowden, as shown in the Introduction of this report. In view of these facts, it is unwise to continue further the term "Yellow Limestone" as a formation name for any of the Jamaican beds.

The highest point at which the Cambridge beds are known to occur is 3,000 feet, near Luidas Vale, St. Catherine Parish.

There are several paleontologic and stratigraphic features of the Cambridge beds which are peculiar, and will require more extensive field work for final explanation. We have reason to believe that the beds are not connected, but occur in broken patches, which, at least in their lower portion, like the Cretaceous beds, represent sporadic colonies of lime making organisms, which found temporary foothold at intervals during a period of turbulent deposition generally unfavorable to a large development of marginal life. These deductions are based upon the fact that in no two localities are the sequence of sediments or association of species identical, while in others the beds do not appear between the Richmond and Montpelier. Furthermore, the fossiliferous horizons of the Lower Cambridge are so like some of the Cretaceous that the one has been frequently mistaken for the other. The mixture of Cretaceous Rudistes and Eocene corals and mollusca at Catadupa, as seen by us, and of Orbitoides and Rudistes in Portland, as noted by Barrett,[3] indicates a transgression of Cretaceous life into the Eocene, and further denotes the anomalous nature of this formation.

These beds, while showing sedimentary relations to the Richmond, undoubtedly represent a transitional step in the deepening which later produced the Montpelier formation. In some places it seems perfectly conformable beneath the latter, while again, as shown by Brown and seen in several places by us, they are unconformable. These apparently irreconcilable conditions can probably be explained upon the hypothesis that the island was undergoing subsidence during the Cambridge epoch, although parts of it were then dry land, which was still further covered by the Montpelier beds during the succeeding epoch. As shown in another chapter, the age of these beds, although containing a remarkable mixture of Cretaceous and Tertiary fossils, is undoubtedly Eocene, and with the Richmond beds they constitute the Eocene system in Jamaica.

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[1] Quart. Jour. Geol. Soc. London, Vol. XXI. p. 56.

[2] Jamaican Reports, p. 311.

[3] Quart. Jour. Geol. Soc. London, 1860, Vol. XVI. pp. 324–326.

The White Limestones. (Oceanic and Coast Series.)

Introductory Statement. — The transitional Cambridge beds grade up into rocks of organic oceanic origin. These are the White Limestone formation of the official Jamaican Reports. They have no genetic relationship with the rocks of the Blue Mountain Series, and differ from them in every physical and chemical aspect.

The interpretation of the white limestones has been one of the greatest problems of Jamaican geology. There have been so many diverse opinions concerning their age and sequence that it is almost impossible to obtain from current literature any approximation of their true relations and significance. The difficulties can be readily seen by any one who reads the conflicting and apparently involved conclusions in the Jamaican Reports. The fragmentary descriptions of their local occurrence are frequently well written, but through lack of correlation and erroneous deduction they fail to clear up the sequence and age of the beds.

All the white limestones have been usually discussed by field observers under one general head, and treated and tabulated as a single formation in the discussion by European geologists who wrote the Appendix, and one would infer that they are not stratigraphically subdivisible. There are numerous references, however, in the body of the Jamaican Reports,[1] from which it is obvious that some such distinctions were at least observed, although the geologists failed to differentiate, name, or correlate them, as we shall endeavor to do in the following pages.

De la Beche[2] included all the rocks from our Cambridge beds to the recent inclusive in his White Limestone, but recognized differences of age therein and correctly referred the basal portion to the Eocene.

Of the field geologists upon the Jamaican Survey, Sawkins held concerning the White Limestone that "Uncertainty has prevailed respecting its precise geological position, but paleontological evidence seems to determine a Mid-Tertiary or Miocene period as the epoch of deposition."[1] Lennox held that the "White Limestone of Jamaica appears to have been deposited slowly and steadily in the bed of a tranquil sea, during the period known to geologists as the Miocene."[2] Wall,[3] through his unfortunate error of mistaking the overlying Bowden yellow marls for the underlying Cambridge yellow limestone, placed the whole of the White Limestone above the Bowden beds now known to be of late Oligocene (Miocene) age. Etheridge, Woodward, Jukes-Browne, Harrison, Duncan, and others, misled by Wall's stratigraphic error, accepted this conclusion. Etheridge stated that the White Limestones were of Pliocene[4] or Post-Pliocene[5] age. Gabb,[6] upon the ground that all the Jamaican white limestones were synchronous with the Post-Pliocene coast limestone of San Domingo, wrongly correlated them as follows: "The Coast formation of Santo Domingo is extensively represented in most if not all the West Indian Islands. In Jamaica, as the White Limestone, it covers more than three fourths of the island and may be computed at 2,000 feet in thickness."[7] Sawkins first considered it as Miocene, but in the end of the book it is put down as Post-Pliocene. Jukes-Browne and Harrison[8] state: "With respect to the age of the [Jamaican] White Limestone the reports of the surveyors are inconsistent with one another; in some[9] it is spoken of as Miocene, in others[10] as Pliocene, and in the Tabular View at the end of the volume it is labelled 'Post-Pliocene.' Mr. Barrington Brown, however, to whom we wrote on the subject, informs us that this last reference was a mistake; that during the course of the Survey and before the fossils were examined there was naturally much uncertainty with respect to its age, but it was finally intended to class it as Pliocene, because it was found to rest on a fossiliferous yellow limestone which was considered by Mr. R. Etheridge to be of Miocene age, and probably late Miocene." The same writers (Jukes-Browne and Harrison), after presenting much evidence to show that these "Yellow Limestones" of Wall and Etheridge — the Bowden beds — were of late Miocene age, and accepting the erroneous deduction that the latter lay beneath instead of upon the great White Limestone Series, concluded that, "this being so, it is clear that the overlying White Limestone Series cannot be older than early Pliocene."[1]

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[1] See Jamaican Reports, pp. 45, 53, 121, 214, 230, 231, 241, 250, 257.

[2] Mem. Trans. Geol. Soc. London, 1829, pp. 169–171.

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[1] Jamaican Reports, p. 23.

[2] Ibid., pp. 23 and 149.

[3] Quart. Jour. Geol. Soc., Vol. XXI. p. 67.

[4] Jamaican Reports, pp. 307 and 342.

[5] Ibid., Tabular View at end of volume.

[6] Geology of San Domingo, p. 110.

[7] Jamaican Reports, p. 307.

[8] Quart. Jour. Geol. Soc. London, 1892, Vol. XLVIII. pp. 219, 220.

[9] As on pp. 23 and 149, Jamaican Reports.

[10] Ibid., pp. 129–301.

The truth is, the white limestones of the Jamaican sequence represent several distinct formations and ages, from Vicksburg to recent inclusive, but that the greater portion of it, as I shall show, is of old Oligocene age. There are even some white limestones in the Cretaceous in Clarendon which are almost lithologically indistinguishable from those of the Tertiary. In recent years English geologists have observed the discrepancies of previous interpretations of the white limestone, and suggested, from specimens of the material sent them, that at least an upper and lower division might be distinguished.[2] Our investigations will show that not two but several subdivisions can be made, and that the rocks hitherto classified under this general head really belong to several distinct formations of two great series, the Oceanic and the Coastal, the former constituting most of the rocks of this character and occupying large areas of the interior upland, while the latter are confined to a narrow belt along the coast.

The older white limestone formations, constituting the greater mass of these rocks, are found in the upland area of the island, and are all of Tertiary age. More exactly speaking, they are of the Vicksburg stage, which is placed in the Eocene by some writers and in the Oligocene by others. The later white limestone formations — including the Coast Limestone of the Jamaican Reports, which we shall describe as the Falmouth Formation, and the Hospital Point Limestone of Montego Bay — are of Pliocene, Pleistocene, and recent age.

There has also been much vagueness concerning the origin of these rocks, accompanied by an opinion on the part of many that they are of coral reef origin. They have been described[3] as "great coral structures, from the débris of which the enormous calcareous development of the White limestone has been derived," and as the "great coralline structure which covers the greater part of the island."[4] Opinions of this nature have caused some writers to believe that all the white limestones were of coral reef origin, and led to the rather careless assertion that reef rocks of great thickness occur in the Antilles at heights exceeding 2,000 feet, when in fact such rocks nowhere except in Barbados exceed 100 feet in altitude or thickness. On the other hand, even the local descriptions of the Jamaican Reports controvert the conclusion that they are as a whole of coralline or coral reef origin, as has also been shown by a few hand specimens collected without reference to horizon and sent to England, studied by specialists, who recognized them as being of foraminiferal composition.

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[1] Quart. Jour. Geol. Soc. London, 1892, Vol. XLVIII. p. 220.

[2] Ibid., p. 219.

[3] Jamaican Reports, p. 24.

[4] Ibid., p. 189.

Not the least important result of our researches will be a demonstration that the larger thicknesses of these limestones are neither of molluscan, coralline, or reef rock origin, but are foraminiferal oceanic deposits and other offshore calcareous oceanic muds composed of organic detritus laid down at depths below that at which reef rocks were formed and in periods of geologic time prior to the appearance of the modern reef building species in the sequence.

The white limestones of Jamaica, both of the Oceanic and Coastal Series, are various manifestations of the vast agency in past times of animal life as extractors of carbonate of lime from sea water, similar to what is now going on throughout the warm regions where the oceanic waters are comparatively free from land sediment. That white limestones, entirely distinct from true reef rock, are now being formed throughout the tropics is a matter of common observation. Wherever calcareous organisms abound around the margins of shores uncontaminated by land débris, the beach wash of calcareous material is rapidly cemented by its own solutions into white limestone rock of various textures; shells into coquina; shell débris and corals into "oölite," which, when wave washed and sea sprayed, like surfaces of the elevated reefs, indurate into hard partially crystallized surfaces. In addition to the near shore deposits, as shown by A. Agassiz and others, calcareous muds of foraminiferal origin are being formed to depths of 5,000 feet or more. When elevated into land these form white limestones.

It is also apparent that white limestones may be partially coralline, as attested by well preserved coral remains, and yet not necessarily of coral reef origin, or in any manner connected with reef making phenomena. All stony corals are not reef builders, and many solitary forms, such as are found in some of the White limestones, inhabit oceanic water to a depth of 1,000 fathoms below the zone of 100 fathoms, below which true reef building corals do not live. Yet it has been customary to call any limestone with sparse traces of these solitary corals "coralline," and from this it was easily transposed into coral reef rock.

In general the tropical white limestones may originate in several ways, as shown in the following table.

ORIGIN OF WHITE LIMESTONES.

I. Organic Extractions from Sea Water.	Remnantal Bottom Accumulæ. Ascending organic growth.	Chalk, Shell, Mud, etc. Reef Rock.
II. Chemical Precipitates.	*a.* Original Oceanic? *b.* Subsequent alteration. Interstitial alteration. Superficial.	Chalk Crystalloids. Crystallized. Sinter Deposits. Cavernous or Honeycomb Rock. Tufa. Sinter.
III. Mechanical Accumulations.	Submarine. Littoral. Terrestrial.	Coral Mud. Lagoon Rock. Coquina. Cantera. Beach Wash Cantera. Cay oölite. Caleche. Coquina. Æolian (Bahama Rock).

In the foregoing processes we have not considered the possibility of the chemical inorganic agencies. Walther has advocated that ammonium carbonate derived from decaying animals may precipitate calcium carbonate from sea water, but this is not the opinion of modern chemists. Reinhard Braun[1] summarizes the various processes producing oceanic lime, and says that most, if not all, massive limestones and chalks are of organic origin.

THE OCEANIC SERIES.

The upland white limestones or Oceanic Series, as we shall call the Tertiary formations under discussion to distinguish them from the later deposits of the Coastal Series, consist of white limestones of varying texture and hardness, and probably aggregate 2,000 feet in thickness. These present a perplexing series of surface and interstitial changes under the influences of solution and oxidation, as explained in their detailed descriptions, which render their study a difficult task. They consist of deeper water organic deposits and are free from coral reef rock, littoral shell agglomerates (such as coquina, cantera, and caleche), beach wash, æolian débris or other clastic formations which characterize

[1] Chemische Mineralogie, Leipsic, 1896, pp. 376–379.

the rocks of the Coastal Series. They contain few macroscopic fossils by which their age can be independently determined, but this is fixed by their microscopic fossils and their position between including fossiliferous horizons, — the underlying Cambridge beds and the overlying Bowden gravels and marls.

In general, the Oceanic Series occupies most of the Plateau region, which practically includes all the island under 3,000 feet in altitude outside of the Blue Mountain district, except its immediate coastal borders. In the mountainous region of eastern Jamaica these rocks occur as a high piedmontal peripheral border around that end of the island. In the western half of the island the beds of the Oceanic Series completely cover the old Blue Mountain Series and occupies the higher summits of that portion of the island.

Owing to the elevation of the Plateau region which took place after the deposition of these beds, and the subsequent contraction of its oceanic borders by erosion and subsidence, the coastward extension of the rocks is truncated and partially embedded near the littoral by the still later formations of the Coastal Series, which are deposited unconformably against them.

The Montpelier Beds. — The Cambridge beds north of Cambridge are succeeded by stratified white limestones and marls containing nodules of flint. The limestones are of non-crystalline (chalky) texture, and usually break with dull, earthy, conchoidal fracture. The texture, fracture, and presence of flints distinguish this formation from others of the great series of white limestones of many ages, which, above the Cambridge beds, dominate in the rock structure of Jamaica.

Concerning the grosser lithology of the Montpelier beds, little can be added to the excellent description of them in Hanover and Westmoreland, given by Charles B. Brown as a portion of the "White limestone," as follows:[1] —

"It consists of thin beds of white limestone interbedded with a soft white chalky marl, the limestone beds invariably containing nodules of flint. The limestones are chiefly soft, but seldom compact or crystalline; they form thin beds, which vary from a few inches to four feet in thickness, and are much disturbed, so as to dip in almost every direction over small areas. The marl beds being interstratified with these of course show the same disturbance and dips, and are similar to them in thickness. The flints and chert contained in the limestone beds lie usually in flattened nodular masses in lines of stratification, and are rarely in beds themselves. They are not connected continuously, but are in long hollow flat masses, and have all the appearances of having been deposited around or in the substance of some organic form which was embedded in the limestone. These flints are chiefly of a brownish pink, brown, and gray colors. At Knockalva and other places in the vicinity the limestone contains small veins of silica, and also has become so thoroughly impregnated with that substance as to be completely changed into a siliceous limestone."[1]

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[1] Jamaican Reports, pp. 250, 251.

Microscopic examinations show that the calcareous beds consist of organic oceanic material, and are composed of the shells of Foraminifera, occasional sponge spicules, and fine crystals and amorphous particles of carbonate of lime, like those usually found in all chalky oceanic deposits. No terrigenous material whatever has been found in any specimens examined. The Montpelier beds are singularly free from molluscan or other visible fossils, except a large species of Orbitoides in its lower beds. Nummulinæ have also been found.

William Hill[2] has studied microscopically a specimen of white limestone, Hanover County, which undoubtedly came from the Montpelier beds. This, according to Jukes-Browne and Harrison,[3] is an oceanic deposit in which "Thick-shelled Globigerinæ, similar to those of the Barbados rocks, are conspicuously abundant, and one or two Radiolarians can be seen in outline."

Some of the flints are also black or gray in color and flattened, oblong in shape, like those of the Upper Cretaceous of England and Lower Cretaceous of Texas; others are round and opalescent. The whitened exterior surfaces of many specimens are masses of silicified Foraminifera, — Orbitoides, Nummulinæ, and Miliolidæ, — and these can be made out in the interior of some of the specimens collected from Montpelier Hill. Similar occurrences of Foraminifera coating the flints have been noted from St Mary. In places they occur in great abundance as requently described in the Jamaican Reports, and are found in no other formation so far as we have observed. Occasionally there are also hard siliceous lumps in the limestone, which suggest that secondary alteration into flints may have been possible. In general, these seem to be silicified lumps of organic skeletal remains. Several specimens of the Orbitoidal flints from St. Mary collected by Wall have been studied by T. Rupert Jones, and published in the Geological Magazine,[1] as further commented upon in the paleontologic portion of our paper. Our studies enable us to show the exact geological position of these specimens, which has been hitherto unknown. The Orbitoides are quite large, and can be collected usually in close proximity to the flints sometimes attached to them. They closely resemble the forms so abundant in the yellow marls of the Chapelton formation and may be specifically identical.

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[1] The description above given refers to Brown's lower division of the white limestone (our Montpelier beds); the upper beds (our Brownstown beds) are more compact and massive, and contain fewer interstratified marls.

[2] Quart. Jour. Geol. Soc. London, 1891, Vol. XLVII. pp. 248, 249.

[3] Ibid., 1892, Vol. XLVIII. p. 180.

Under the microscope the entire mass of most of the chalks collected by us consists of Globigerinæ, which at present form great deposits on the ocean's bottom between 1,500 and 2,900 fathoms. The specimens collected from Montpelier Hill, the foothills north of Savanna-la-Mar, Dover, between Annatto Bay and Buff Bay, St. Margaret, and near Buff Bay, — widely separated localities, — were entirely made up of Globigerinæ.

The Montpelier beds are best exposed in the hills of the north side of the island in the bluffs of the back coast country along the north coast road, notably near St. Ann, Falmouth, and Montego Bay; from Port Antonio westward into Hanover Parish; and typically along the line of the Jamaican railway between Montpelier to Montego Bay, and at many other places around the island. They are exposed almost continuously across the island in the parishes of Westmoreland and Hanover, between Anglesea near the coast, five miles east of Savanna-la-Mar, and Montego Bay via Montpelier, where they have been well described by Charles B. Brown under the name of "White Limestone," as previously mentioned. Here they constitute most of the uplands or hills of the back coast country, except where eroded through in the processes attending the making of the sinkhole and cockpit countries. In the valley in which Montpelier is situated, and also that near the heads of Thicket and Morgan Rivers, many peculiar isolated buttes standing upon a floor of Cambridge and Richmond beds are made up of the Montpelier limestones; also the railway cuts between Montego Bay and Montpelier are composed of them.

They are repeatedly exposed in great thickness along the front of the back coast hills along the coast road from Montego Bay to St. Margaret Bay east of Port Antonio. At Cinnamon Hill (St. James) the beds are almost vertical, inclining to the north coast. Here the limestone of homogenous texture is in thin evenly bedded layers at the base, succeeded by thicker beds, both of which contain flints and large Orbitoides. The exposure is very near the base of the formation, the Richmond beds outcropping at no great distance. Between Falmouth (Trelawney) and St. Ann Bay (St. Ann Parish) the whole north front of the back coast country is made up of these beds, as described on the upland road from Runaway Bay to Falmouth via Brownstown. Near Landovary about five miles west of St. Ann Bay, the back coast bluff consists of the basal portion of the Montpelier beds with flints in contact with the Richmond gravel, as shown in the accompanying Figure 21. At St. Ann Bay, the base of the Montpelier beds is also seen in the bluffs. The rocks at Landovary have a strong south dip. In St. Mary Parish the road from Runaway Bay to the summit of the hills of the back coast country (altitude 1,450 ft.) *en route* to Brownstown, passes over at least 1,500 feet of white limestone, the lower 500 feet of which are composed of the Montpelier beds with flints, grading upward into the Moneague beds. From Retreat (St. Mary) to Falmouth in Trelawney, the Montpelier beds are occasionally well exposed along the upland interior road, especially in the bordering slopes of Hampshire Valley, notably near the Blanksford and Highgate estates. From the summit of the divide between the Hampshire Valley and the sea, 920 feet of the flint bearing beds are exposed between that point and Falmouth. On the highway from Moneague to St. Ann, in going from the high-

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[1] Quart. Jour. Geol. Soc. London, 1864, Vol. XIV., foot-note page 104.

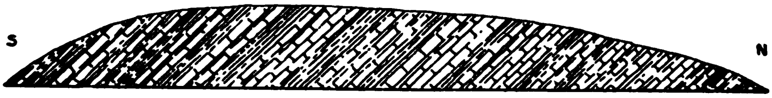

FIGURE 21. Montpelier Formation at St. Ann Bay.

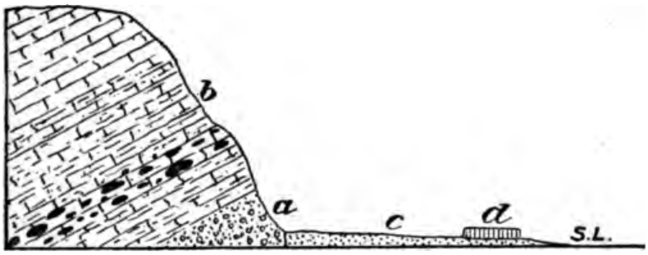

FIGURE 22. Section at Landovary. *a*, Richmond Beds; *b*, Montpelier Formation; *c*, Coast Plain; *d*, Elevated Reef, Sea Level.

lands to the coast, the Montpelier beds are magnificently displayed in the road cuttings. Here the road descends through a thousand feet of the white limestone, the lower half of which consists of the Montpelier beds.

The hill country back of Port Maria is largely made up of the Montpelier beds, which are also well exposed near Dover, where Globigerinæ chalks with flints make up the beds.

At the bluffs from one to two miles east of Buff Bay, which are more fully described under the head of the Bowden beds (see Figure 23 and Plate XXVII.), the Montpelier flint beds are seen beneath the Buff Bay formation. They are here exposed at and just east of the tunnel. This section shows gradation upward into chalks without flints, and reveals clearly that the Montpelier beds are stratigraphically below the Bowden Oligocene. Three miles east of St. Margaret Bay, at a high bluff, there is a good exposure of the Montpelier flint beds. The collections of the chalky limestone in which these flints were embedded consist of Globigerinæ. The beds here have a strong south dip. From the locality above mentioned to near Port Antonio, the flint bearing beds frequently outcrop in the bluffs and are capped by the Bowden beds.

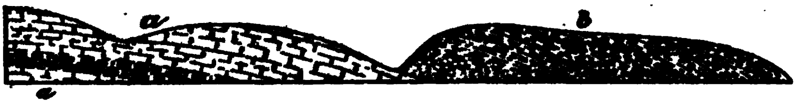

FIGURE 23. Section of Bluff East of Buff Bay. a, Montpelier Beds, with Flints; b, Bowden Marls.

The high bluffs backing the bay about one mile west of Port Antonio afford a good exposure of beds which apparently represent a phase of the Cambridge beds grading up into the Montpelier. Here the bluff is made up entirely of white limestones of varying texture and greatly disturbed. The lowest rock exposed is very hard limestone, subcrystalline in texture in some places, and in others showing thin lamellæ of blue-black clays suggestive of the Cambridge beds. From the lower and harder limestones casts of several of the molluscan species of the Cambridge beds were collected, including a gigantic Nerinæa and a Lucina. These fossils, together with the impurities of clay shale, suggest that this portion of the beds belongs to the Cambridge formation. Just above the foregoing strata there is a soft pulverulent bed of granular texture which is composed entirely of Cambridge Miliolidæ. The still higher strata of the bluff are apparently the Montpelier beds with flints. East of Port Antonio there are several other outcrops which belong to the Montpelier beds; from the literature we infer that they constitute the summit formation of the John Crow Ridge.

On the south side of the eastern portion of the island beds corresponding to the Montpelier have been noted in a locality mentioned by Sawkins,[1] near Orange Park, in St. David, where their relations to adjacent formations can be seen, and in Long Mountain back of Kingston. In our reconnoissances of this portion of the island, beds apparently belonging to this formation were seen between Bath and Bowden.

No exposure of the Montpelier beds on the south slope in the region between Long Mountain east of Kingston and St. Elizabeth is known. In fact the formation seems to be missing in the Bog Walk and Clarendon sections, though it may be represented there by a hiatus between the Cambridge and Brownstown formations. In St. Elizabeth the beds are again well exposed apparently unconformably below the Brownstown at Springfield and thence to Pisgah. From the details above given it is apparent that before its dismemberment during later erosion this formation completely girdled the island and entirely buried the old Blue Mountain Series in the western two thirds of its area.

The thickness of the Montpelier formation is difficult to determine, owing to lack of continuous exposures. Our observations have led to the conclusion that they do not exceed 1,000 feet. Everywhere these beds show great disturbance, but not to the degree of the Blue Mountain Series, usually consisting of more open folds.

The Montpelier beds are the deepest sediments preserved in the geological structure of Jamaica, and represent the culmination of the great subsidence initiated in the Cambridge epoch. Judging from the rapid transition between the littoral Cambridge formations and the chalks of the Montpelier formation, this subsidence must have been rapid in geologic time.

The age of the Montpelier beds most probably corresponds to that of the late Eocene (old classification) now called the early Oligocene, agreeing approximately with the position of the Vicksburg stage of our American Tertiary. This inference is based upon the position of the beds above the undoubted Lower Eocene of the Cambridge formation, and below the undoubted late Oligocene of the Bowden formation, together with the occurrence of Orbitoides mantelli.

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[1] Jamaican Reports, p. 53.

The Moneague Formation. — The Montpelier beds grade up into more massive limestones, white in color, firmer in texture, often semi-crystalline, sometimes containing casts of fossil mollusks and solitary corals, and occurring in well defined bands of stratification from one to five feet in thickness. More massive texture and regular bedding especially distinguishes this formation from the other white limestones of the island, such as the chalky rocks of the underlying Montpelier and the irregular lumpy texture of the overlying Cobre formations. These rocks contain many cavernous moulds of Mollusca and single corals, indicating that a considerable amount of shell débris may have accompanied their original deposition. The fossils obtained near Ewarton, Retreat, and Cinnamon Hill, in a firm limestone matrix, were mostly poorly preserved moulds of corals and mollusks, which the paleontologists could not determine.

These rocks become very cavernous through interstitial solution and the surface is usually indurated and karrenfeldate. Sometimes the limestone is in small angular fragments or lumps with sharp edges, as if it had been shattered by some great stress, — a condition which may in part be due to shearing, but is also largely produced by irregular consolidation and solution. This angular aspect is well shown on the right hand side of Plate XXVI.

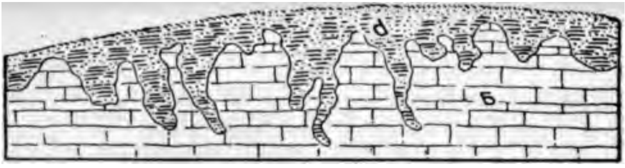

FIGURE 24. — Residual Clays in Limestone Sinks at Frankenfield.

In places the Moneague formation weathers into a yellow ferruginous clay subsoil, constituting a thick surface coating. This is the residual clay and iron which remains after the transportation of the soluble lime by water. Exposures along the railway between Porus and Ipswich show some beautiful subaerial alteration. Deep natural wells or pits are seen in the limestone. These are filled with the residual clay, similar to the occurrence previously shown in my report on Cuba. Where the soils of these limestones have been cultivated the ruinate is

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[1] Notes on the Geology of Cuba. — Bull. Mus. Comp. Zoöl. at Harvard College, Vol. XVI. No. 15, 1875, Plate I. Fig. 7.

usually grass-covered and not retaken by shrubs and trees, as in the case of the abandoned soils of other formations.

William Hill has made microscopic examinations[1] of a rock from Mile Gully near Kendall in the centre of the island, 1,100 feet above the sea, which apparently belongs to the Brownstown formation. The nature of this material, as described by him, is as follows: "Mile Gully, specimen 1. Angular fragments set in a matrix of what was in all probability fine mud, but now granular calcite. The structure of the fragments and mud is obliterated by general crystallization. Mile Gully No. 2. Made up originally of large fragments set in matrix of fine mud. Structure of fragments mostly lost, outline shown by patches of crystalline calcite. Fragments of Lithothamnion and fragments of probably Amphistegina. Contains also ossicles of a recent starfish. Mile Gully No. 3. Patches of clear crystalline calcite in a matrix of granular calcite. One or two fragments can be seen to be Echinoid plates or ossicles."

Jukes-Browne and Harrison state that these specimens from Manchester and St. Elizabeth were found to resemble coral limestones,[2] and Hill also compares them[3] to rocks of this origin, but from these descriptions we do not see the resemblance, — especially to rocks of reef origin or reef débris.

From their usual association with and occurrence above the Montpelier beds, there is little doubt that they were continuously deposited with the latter, and possibly may represent shallowing but nevertheless deep water beds after the culmination of the Montpelier subsidence. Our knowledge of the upper contact of these beds is very deficient. In Clarendon and St. Elizabeth they clearly occur below the Cobre and Porus (Bowden) formations.

These beds occur at many places in the western half of the island, especially in the vicinity of Brownstown and Retreat, St. Ann Parish. At these localities, as in Trelawney, St. James, Hanover, and Westmoreland, they occupy the highlands of the interior, constituting the surface formation out of which the cockpit country is largely eroded. Beds of allied lithologic character are exposed at Moneague in the excellent cuttings along the Montego Bay between Ipswich and Catadupa; at Retreat, Trelawney Parish; at Cinnamon Hill, St. James Parish; on the north coast road, and in the bluffs at the railway station at Ewarton.

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[1] Quart. Jour. Geol. Soc. London, 1891, Vol. XLII. pp. 248, 249.

[2] Ibid., Vol. XLVIII. p. 219.

[3] Ibid., Vol. XLVII. p. 248.

With the probable exception of the Mile Gully ridge, nearly the whole surface of the northern half of Manchester Parish, as crossed in a northwest and southeast direction by the Jamaican Railway line, between Porus and Phœnix Park, is composed of the stratified beds of the Moneague formation similar to the exposures at Ipswich, and consists of alternations of hard compact limestone, dull gray-white in color, semi-crystalline in texture, with alternations of white calcareous chalky marls. The beds are quite cherty in places, which, with their stratigraphic proximity, suggest the nearer relationship of these beds to the Montpelier than to the Bowden formation. Casts of fossil Mollusca and small single stems of branch coral like those found at Retreat also occur. These beds are especially well displayed in the cuttings of the river near Williamsfield.

At Ewarton the railway terminal is quarried out of the beds which occur in massive uniform layers several feet thick. A few molluscan fossils weather out upon the surface of the rocks, but they are too indistinct for identification. From Ewarton to Moneague the beds can be seen from the highway, arching over the western border of the St. Thomas basin. At Moneague they have wide surface development, especially to the westward via Brownstown, Stuart Town, and Retreat. At Ipswich and thence on towards Catadupa the regular bedding is beautifully seen in the deep railway cuttings, as shown in Plates XXV. and XXVI.

We are not prepared to state positively that the beds of these different localities are identical, for paleontologic material is very rare, but from their resemblance we incline to think that future research will show them all to be parts of the same formation.

The Cobre Formation. — Between the town of Bog Walk,[1] on the south side of the interior basin valley of St. Thomas-in-the-Vale, and Spanishtown, on the Liguanea Coastal Plain, the Rio Cobre cuts a canyon through a white limestone plateau separating the two localities. This canyon, known as Bog Walk, is one of the great scenic features of Jamaica, and terminates at the Liguanea Plain as a true boca,[2] from which it took its original name, Boca del Agua.

The canyon of the Cobre is about 200 to 300 feet deep, with sloping sides, a fine view of which is shown in Plate X.; it is cut entirely out of certain problematic beds of white limestone, which will be described as the Cobre formation. The slopes are usually covered with dense vegetation, good rock exposures not being plentiful except in the immediate streamway. Even then they are encrusted with tufaceous material, so that their structure and arrangement are largely concealed. The following extract from the notes of our traverse of this canyon will give an idea of the composition and structure of these beds. Miles read north from Spanishtown.

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[1] English corruption of Boca del Agua.

[2] Among other uses Boca is applied to the mouth of a canyon debouching upon a plain.

0–4½ miles.[1] — The river flows in a V-shaped alluvial plain indenting the canyon to this point.

4½ miles. — A road metal quarry reveals the texture of the white limestone, which is here composed almost entirely of small angular lumps of firm limestone, chalky white in color, associated with a matrix of very fine pulverulent chalky sinter, free from clay, but commonly termed "White Marl," as are all other soft formations. There are also a few small lumps of compact gray or dove colored limestone (dolomite?). This formation is of cavernous or "honeycombed" texture and weathers into irregularly crystalline limestone, constituting ragged karrenfelder on horizontal surfaces. Furthermore, the faces of the bluffs are in places coated with self-derived tufa, and are so indurated that these outcrops have a massive non-stratified appearance. This limestone differs from that of the Cambridge and Montpelier beds in the entire absence of lamination or traceable lines of bedding.

4½–8½ miles. — The limestone is continuously exposed in the vertical bluffs through which the river cuts its way. No trace of bedding can anywhere be made out, and the surfaces of the cliffs are everywhere very indurated.

8 miles. — The inclination of the beds, hitherto indeterminate, shows a strong south dip.

8½–9 miles. — The vertical cliffs show dips to south of 30° (estimated), the angle increasing in steepness as we go north. While these exposures are more massive looking than those before noted, quarries reveal the same texture as that noted at Mile Post 4½.

9–11 miles. *Bog Walk Village.* — Here the canyon ceases, and the country opens out into the interior valley of St. Thomas-in-the-Vale. Superb exposures of the Cobre limestone and its basal conditions are shown in the bluffs at the upper end of the canyon, as illustrated in Figure 25.

The pebble and buff-colored marls grade into the limestone, and represent its initiatory littoral. A few poor and indeterminate casts of fossil

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[1] From Spanishtown.

Mollusca occur in these beds. The lumps in the marl are largely fossils; three specimens are Echinoids, and one is a large Conus, two inches long. Casts of Natica and Cypræa were also recognized, as well as two species of coral, — one a simple form, the other a compound form, but both so poorly preserved as to be indeterminate. None of these forms suggest the Bowden fauna except the simple coral, and probably they represent a slightly earlier and preceding horizon.

From Bog Walk Station to a point where the highway to Linstead crosses the railway track, one and a half miles due north, following the south margin of the basin valley, the surface exposures consist of later alluvium. At the last mentioned point the railway cuts through an inlier of white limestone of the Cobre type. This exposure contains an abundant molluscan fauna, but all the specimens are poor casts, among which the genera Bulla, Arca, Cardium, and Lucina are evident. No corals or Echinoids were found. A few miles farther, at Linstead, the Moneague beds appear, apparently beneath this section. The aggregate thickness of the limestone of the Cobre section cannot be less than 1,000 feet, and is probably much more.

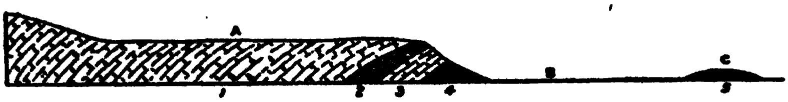

FIGURE 25. Section of Northern End of Bog Walk Canyon.

1. White stratified Cobre Limestone with Marl Pit.
2. Conglomerate of small Igneous Pebble.
3. Buff colored Limestone, banded.
4. Buff, granular, laminated Marl, with little Conglomerate, oxidizing Red.
5. An Outlier to North of this Locality, which will be described later.

The extent of the Cobre formation is not completely determined. We have personally seen the formation only on the south side of the central portion of the island. Good exposures of it are seen in Clarendon along the highway from May Pen Station, on the Montego Bay Railway, and Chapelton. Here the limestone has the same general character as that of the Bog Walk section, and constitutes the summits of the Minho Mountains. Between the Minho River and Retreat,[2] the limestone is underlain by more massive bedded layers resembling the Moneague for-

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[1] Echinolampas or B. thiiopygus.

[2] Not to be confused with Retreat in Trelawney, previously mentioned in discussing the Brownstown formation.

mation. In this region the Cobre formation is very much honeycombed, and weathers into blood-red soils. At one place where laborers were blasting unusually large masses of the limestone, specimens from its interior were secured, which clearly showed the red iron blotches in the interstitial cavities.

There are a number of isolated outliers of this formation standing in the midst of the Liguanea and other plains composed of later alluvium in the parishes of St. Catherine and Clarendon, as shown in Figure 26.

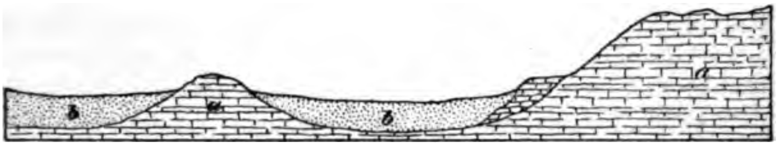

FIGURE 26. Outlier of Limestone in Liguanea Plain, near Spanishtown. *a a*, Cobre Limestone. *b b*, Kingston Formation.

These are of the type known in America as monadnocks. Two of these may be conveniently seen on the Kingston road a mile or two east of Spanishtown.[1] These consist of the same limestone as that seen in the Bog Walk section (see Fig. 25).

At the convict quarry back of Rock Fort, about four miles east of Kingston, where Long Mountain bluffs against the seacoast, a superb exposure of limestone has been made by quarrying. It is so lumpy that it is worked by the pick and used for road metal. Under the microscope it is composed of numerous undetermined species of Foraminifera, entirely different from those of the Montpelier and Cambridge beds. In the western group of parishes, forming the county of Cornwall, it may constitute the summit formation and pointed hills of the cockpit country. This idea is suggested by the lithologic aspects of the rocks comprising these hills, and from outcrops in Manchester along the highlands bordering the Montego Bay Railway. Close research has not been made to determine this. A prominent feature of the Cobre formation is the blood-red residual subsoils which everywhere result from its surface decay.

From the Bog Walk section it is evident that the Cobre formation lies stratigraphically above the supposed Moneague beds at Ewarton and below the May Pen formation. Its relations with the Bowden beds of our section are not established. It apparently occupies an intermediate position between the Moneague and the Bowden.

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[1] Lennox (Jamaican Reports, pp. 149–151) described the formation of these hills under the name of the "Port Henderson Limestone."

The Coastal Series.

Older Portion.— The Bowden and Allied Formations.[1]

This series includes a class of formations which represent the products of events more recent in the history of the Jamaican sequence than those hitherto enumerated. Its members occur around the coastal perimeter of the island, principally along the margins of the sea at altitudes nowhere exceeding 250 feet, and deposited unconformably against the sides of an older mainland. Here and there on the south coast they fill previously formed erosion plains. They were all made during epochs subsequent to an epoch of elevation whereby the white limestones of the Oceanic Series and all preceding formations had been elevated into land, had undergone tremendous denudation, and had again suffered partial marginal subsidence.

They are of four types of formations, to wit: beds of impure marine limestone, gravel, and marl; alluvium of the Kingston type; elevated coral reefs as illustrated in the Barbican and Hopewell formations; and littoral deposits of calcareous mud, with embedded fossils of contemporaneous origin with the elevated reef formation. The four types in their general lithologic characters are analogous to the marine littoral, alluvial, and coral reef formations now being made around the margins of Jamaica.

The Bowden Beds.[2] — The Bowden and allied formations of later Tertiary age constitute the older beds of the Coastal Series and are all marginal to the main upland mass of the island. They apparently represent a series of fringing formations extending around the older Plateau region. These in turn are bordered by still later and lower lying formations.

Along the south coast of the east end of the island, between Morant Bay and Port Morant, there is an extensive occurrence of gravel beds less than 50 feet in thickness, containing rolled specimens of nearly every species of volcanic rock found in the island, which grades upwards into an impure stratified brown and buff colored marl, the latter having a thickness of 200 feet as measured in the bluff upon which Captain Baker's house at Port Morant stands. The loose gravels at the base of this section have a very recent appearance, a deception which is further aided by the fact that they occur at beach level, and contain perfectly preserved fossils resembling modern shells. The fossils heretofore reported from Bowden are found in the gravel bed, and, less abundantly, in a few feet of the lower part of the overlying marls, at the foot of the hill, at the beginning of the road leading up the hill to Captain Baker's, and in such abundance that as many as 400 species of Mollusks have been determined by Dr. Dall from two barrels of material collected by Messrs. J. B. Henderson, Jr., and C. T. Simpson and the writer. A few specimens occur higher up the hill, while near the summit there is a body of firm crystalline secondary limestone containing moulds of the characteristic fauna. The physical characters of this formation can be traced from Bowden to Morant Bay and beyond nearly to Yallahs Island, but there it loses its identity. On the road from Bath to Bowden its position above the Cambridge beds is fairly well revealed.

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[1] The "Yellow Limestone" of Etheridge, Wall, Jones, Woodward, and others; not the "Yellow Limestone" of Sawkins and Brown.

[2] This name is adapted from Dall.

The stratigraphy of the formation has not hitherto been presented correctly, although in the Jamaican Reports under the name of the "Yellow Limestone" it was partially confused with the entirely different beds herein described as the Cambridge formation, and the gravel beds were mapped with the Pleistocene and recent formations.[1] Hence its identity as a formation did not appear in these Reports.[2]

It is only on the south coast of the east end of the island that the Bowden beds have the characters mentioned. It is evident that the formation with modified lithologic features occurs elsewhere on the island, for the Bowden fossils have been found on the opposite side by us, and reported from round the district of Vere near the coast of Clarendon by other writers, in formations of quite a modified lithologic nature. Probably the Buff Bay, May Pen, and Porus formations, next to be described, are allied and synchronous deposits.

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[1] Careful search of Barrett's writings show that he made two brief references to these beds. In one place (Jamaican Reports, page 44) he merely mentions "beds of marl, sand and conglomerate of the Bowden series," and alludes to sections and further descriptions to be given, but which were never published. Upon another page (Ibid., pages 45, 46), under the head of "gravels, clay, and yellow marl," he gives the following account of what we now know as the typical Bowden locality: "On the northeastern portion of the Port at Bowden we find the upper beds both thicker and more inclined (10° S. E.) than on the west, and are also more fossiliferous. Below the Pteropod marl are beds of the most perfect Tertiary shells yet known on the island."

[2] The fossils of the Jamaica Survey from Bowden in the Museum at Kingston are also labelled the "Yellow Limestone."

The Buff Bay Beds. — A formation closely allied to the Bowden beds is exposed in the superb coast bluff one mile east of Buff Bay on the north side. A good view of this is given in Plate XXVII. and the stratigraphical relations shown in Figure 23. This exposure consists of over 100 feet of bluish white, earthy, semi-indurated marl, containing very finely worn pebbles of igneous rock scarcely as large as peas, sparsely disseminated through it. It is in evenly bedded strata sometimes separated by thin laminæ of bluish calcareous clay. The beds contain many fossils, most of which crumble into calcareous powder on exposure to air, but some are sufficiently preserved to enable Vaughan to identify the corals. These beds at Buff Bay rest directly upon a pure white chalky marl, which in its lower part grades down into the Montpelier beds seen at the railway tunnel.

The beds of this locality are slightly more calcareous, but nevertheless are texturally related to the marl exposed at Bowden; they likewise contain gravel in very finely rolled particles, possibly indicating that the beds are a slightly deeper water stage than those exposed at Bowden. Probably the Bowden exposures represent the littoral of the formation, while those of Buff Bay are of slightly deeper water origin. The identity of the two localities is proved by the fact that one of the typical and peculiar fossil corals of Bowden occurs in the Buff Bay material as determined by Vaughan.

At Navy Island, a detached portion of the mainland lying off Port Antonio, there are impure yellowish clay marls and thinly bedded limestones. These are also seen on the point of mainland at Port Antonio on which the hotel of the Boston Fruit Company is situated. The beds at Navy Island have also been correlated with the Bowden beds by Duncan and Wall.[1]

The May Pen Beds. — At May Pen Parish of Clarendon, on the Montego Bay Railway, and extending from there westward to Clarendon Park and eastward to near Old Harbor, along an east and west line corresponding with the width of the parish of Clarendon, there outcrops a peculiar formation corresponding in general position to the Bowden beds of the east end. This material consists of a loosely consolidated mixture of yellow colored limestone lumps and clay marl, and contains many casts of Mollusca. The only good exposures we have seen are in the railway cuttings. The beds at May Pen clearly rest against the southern margin of the Cobre formation, as seen immediately back of the station in May Pen village; it apparently occurs along interior margins of the plain between Old Harbor and Clarendon Park, known east and west of the Minho as Harris Savanna and Lime Savanna respectively, and is thus apparently deposited along a former coastal margin which once here attinged against the low back coast uplands through which the Bog Walk Canyon is cut, and previously shown to be composed of the Cobre formation.

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[1] Quart. Jour. Geol. Soc., Vol. XXI. p. 14.

Stratigraphically the May Pen beds occupy a position immediately preceding that of the ancient alluvial deposits elsewhere described as the Kingston. Fossils are numerous at May Pen, consisting entirely, so far as we observed, of indeterminate casts of Mollusca, being free from corals, especially of the reef building species. Further study of this locality is very desirable.

The Porus Formation. — From the crossing of the Cobre to beyond Porus there are in the railway cuts many fine exposures of a formation resembling that at May Pen, consisting of loose, coarse textured yellow clay marls accompanied by irregular lumps of limestone and containing poor casts of fossils. Sufficient material was not obtained from it to determine with exactness its stratigraphic position, although it is, in general, to the coastward of the Bog Walk limestone, and apparently above it. The fossils which we have seen from it have facies more resembling those of the Bowden beds than of the later formations presently to be described.

There is also evidence that beds analogous to those of Bowden occur on the south coast of Clarendon Parish at the foot of Round Mountain near Bath, which, according to Sawkins,[1] contain fossils of the same genera as those found at Bowden (Port Morant). A coral from this locality described by Duncan, and an Orbitulina by Jones, indicate further identity of the horizons. Unfortunately, the writer has not visited this locality.

Of the beds described, only the Buff Bay and Bowden localities can be correlated with positiveness at present. The inclined position of the former shows that they participated in some of the later orogenic movements of the island.

The final key to the Jamaican sequence depends upon the determination of the upper relations of the Bowden and allied beds. That they clearly overlie the greater mass of the white limestones I am most positive, and are not at the base of all the white limestones, as asserted without presentation of proof by previous writers, whose conclusions, as stated in the Introduction to this work, are known to have been based on the erroneous correlation of these beds with the Cambridge Yellow limestones which we know underlie the white limestones as a whole. That they lie entirely above the vast thicknesses of white limestone included in the Montpelier, Moneague, and Cobre formations is certain, and we have no reason to believe that any great mass of white limestones succeed them, the white limestones of the later formations being relatively trivial in comparative thickness.

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[1] Jamaican Reports, p. 162.

THE COASTAL SERIES. — LATER PORTION.

The Manchioneal Formation. — On the abrupt east coast of the island, notably at Mulatto Bay and Manchioneal, and at various localities between those points, there is a marine formation composed of alternations of loose yellow marl and lumpy white limestone slightly resembling the May Pen beds, but differing in that it possesses in places well defined bedding planes and sometimes alternations of evenly bedded marl and impure limestones.

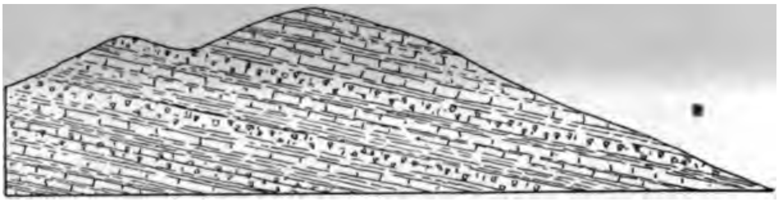

FIGURE 27. Exposure of Pliocene at Mulatto River with Coral Heads.

East of Pellew Bay are exposed 200 feet of a formation consisting of rotten and honeycombed white lime boulders, embedded in white marl which weathers exteriorly into yellow clay. Against the eroded sides of this is an unconformable deposit of elevated reef rock.

At Mulatto River the road cuts through superb exposures, showing 200 feet of beds similar to the foregoing, except that the limestone and marl are in persistent uniform alternations dipping strongly to the north. In these beds may be seen occasional heads of reef coral. About the middle of the section there is a ten foot stratum almost made up of the latter, which clearly represents old reef rock, the oldest thus far encountered in the ascending series of the Jamaican section. The accompanying figure will give an idea of these beds.

From Priestman's River to Manchioneal this formation makes a bluff 150 feet high, located slightly back of the shore line until within one mile of Manchioneal, when it approaches the edge of the sea. In the bluffs encountered just north of Manchioneal along the coast road are exposures of the formation 100 feet or more thick. Careful search for fossils in this bluff revealed only a few undetermined casts, — a few mollusks, a single species of reef building coral, as determined by Vaughan, many specimens of a Terebratula which Charles Schuchert has kindly studied as elsewhere reported, and a single pteropod.

The Manchioneal formation continues south of Manchioneal as far as Priestman's River at the east end of the island, where our traverse left the seacoast and turned inland via Bath, reaching it again at Bowden. The beds may also be exposed along the intervening strip of coast between Priestman's River and Bowden.

Barrett has reported from various localities at the east end of the island between Port Antonio and Morant Bay, at Old Harbor, Manchioneal, and capping the hill at Bowden, a formation to which he gave the name of the Pteropod Marls.[1] His lithologic and stratigraphic descriptions of this formation are so meagre that it is difficult to identify the beds to which he intended the name should be applied. Even why it was called Pteropod Marl is not apparent, as only three species of pteropods were reported from it. Others alleged that it was composed largely of Foraminifera, thirteen species of which, as determined by T. Rupert Jones, are enumerated on page 314 of the Jamaican Reports. Our reconnoissance of the east end of the island was largely made to study this formation, but we were unable to recognize any beds corresponding to it as a unit. We found marls with pteropods both at Manchioneal and at Bowden, each of which localities was specifically mentioned by Barrett, but inasmuch as these two places represent outcrops of distinct formations, the same name can hardly be applied to them, although there is but little doubt that they succeed each other stratigraphically.

Marine Pliocene formations analogous to the Manchioneal beds of the east are but sparsely represented in the western part of the island. At only one locality have we seen anything analogous to it. From eight to nine miles southwest of Montego Bay on the coast road at and near Round Hill, there are extensive beds of yellow marl, resting upon a foundation of the Montpelier white limestone, which occupy the stratigraphic and topographic position of the Manchioneal beds of the east coast and closely resemble them in composition and texture. This formation is apparently the oldest of the Coastal Series of this vicinity occurring by later and unconformable deposition in a pre-eroded plain back of Montego Bay, which in former times was evidently a bight into the present back coast hills.

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[1] Jamaican Reports, p. 82.

It is our opinion that the position of the Manchioneal beds along the south coast west of Yallahs Mountain is largely occupied by the older part of the Kingston formation next to be described.

Nowhere have we seen the Manchioneal beds occur at a higher altitude than 300 feet, if that high. Barrett[1] mentions them as occurring at a height of 140 feet at Blue Hole, and 300 feet near Port Antonio.[2]

From the low position of the Manchioneal formation adjacent to the coast and unconformably against the older and more disturbed white limestones, it is evident that it was a marginal fringing deposit. Its stratigraphic position above the Bowden formation and below the undoubted elevated reef rock to be described later, as well as the paleontologic evidence of its pteropods and Brachiopoda, indicate the Pliocene age of this formation. The contained corals, here poorly developed and occurring in increasing proportions in the succeeding beds, mark the first definite appearance of the marine reef building species in the Jamaican sequence.

The Kingston Formation.[3] — The extensive gravel covered plains of the south side of the island of which that known as the Liguanea is a type, have been fully described in the chapter "Geography and Physiography," Part I. of this Report.

These plains are composed of formations consisting mostly if not entirely of aggradational material derived from the adjacent uplands of the mountains and plateau. This material varies in composition, being mostly detritus of the Blue Mountain Series to the east of the Rio Cobre and largely white limestone débris to the west of that stream.

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[1] Jamaican Reports, p. 66. From his submarine explorations of the adjacent seas he estimates that similar deposits are now forming at 150 fathoms (900 feet), and that the sea bottom has been elevated this amount plus the present altitude of the formations (300 feet), or a total of 1,200 feet since they were made.

[2] Ibid., p. 82.

[3] The material of the Kingston and allied formations are well described under the general head of "Alluvium," in the portions of the Jamaican Reports dealing with the parishes of St. Andrew, St. Dorothy, Vere (now a district of Clarendon Parish), and St. Catherine. See Jamaican Reports, pages 101, 102, 142, 149, 161, and 186. They are also discussed under the head of "Plains" on page 100 of the same Report.

It has been successively accumulated through several geologic epochs, and may ultimately be classified into several distinct terraines. For the present, however, we shall recognize but two principal stages, — an older one, to which the name of Kingston will be applied, and a newer one, which will be called the Montego.

The Kingston formation is the oldest of the formations of old gravel and other alluvium occurring upon the plains of the Liguanea type. This is the formation upon which the city of Kingston and suburbs are built, including the strip of land known as the Palisades, and the plain extending back of Kingston to the foot of the mountains (see Plates VI. and XIX.). The material consists of boulders, gravel, and pebble of varying sizes, usually very angular, and representing every known material of the Blue Mountain Series. These are embedded in a matrix of dull red arenaceous clay, producing a chocolate soil and derived from the Minho beds so conspicuously exposed *in situ* in the mountains north of Kingston.

The thickness of this formation is unknown, but over 200 feet are exposed in the thalweg of Hope River, and probably fully this thickness is concealed. It is even likely that it may be nearly a thousand feet in places.

To the west in St. Catherine the material is similar in composition to all the rocks of the mother region drained by the Cobre. Sometimes it grades into a true marine marl, including some white limestone débris.

Concerning the origin of this material in St. Andrew, there is no doubt but it has been deposited by Hope River, as it debouched from the mountains. While most of the material was originally estuarine, some of its upper layers were made by talus fan deposits similar to those now seen in the arid region of North America where the mountain streams debouch upon the desert plains.

As a whole, it represents excessive deposition, first as estuarine or littoral material during an epoch when the coasts were submerged, and later talus deposits of subsequent epochs, when the land was rapidly rising and stream erosion was very active, as discussed more fully in Part I., p. 39, of this paper. The alluvial deposits in the bottom of the larger interior basins are also closely synchronous with the Kingston formation, and it is probable that these basins are products of the same great erosion epoch which preceded the Kingston deposition.

Fossils[1] are generally missing from the Kingston formation; speculation concerning its age must be founded entirely upon stratigraphical relations. In our opinion it is clearly older than the elevated reefs of the Barbican and Hopewell formations of presumable Pleistocene age, and younger than the Bowden formation, being nearly allied by position to the age of the Manchioneal which we consider Pliocene.

The present beds of both the Hope and the Cobre Rivers deeply indent the Kingston formation, cutting far below the surface of the plain. The alluvium of these stream valleys and their general level constitute distinct deposits which are later described under the head of the Montego formation.

The Elevated Reefs. — The coast of Jamaica, like many of the other West Indian Islands, is in places bordered by a peculiar formation composed of rocks which were once growing coral reefs similar to those now bordering the island, and which have been raised above sea level by general regional elevation in late geologic time. These formations are found in small, limited, interrupted areas in Jamaica immediately adjacent to the coasts, and at altitudes of less than seventy-five feet. They do not have the wide areal development which is seen on the north coast of Cuba, nor do they veneer the higher summits as in Barbados.

The elevated reef rocks usually constitute horizontal beds of strata from ten to forty feet in thickness. These have a more or less massive exterior, due to surface induration, but when cut into, as they frequently are by the undermining of the sea or in the construction of highways, their interior structure is seen to consist of porous limestone material of varying texture, always more or less minutely honeycombed, and of irregular hardness, with red oxidized spots or yellow patches here and there. They show all degrees of induration, from that of the practically unchanged reef material to firm semi-crystalline white limestones.

These rocks are composed of coral heads of various sizes embedded in a matrix of marl, — the latter being sometimes indurated into limestone. The heads usually have the erect position which they maintained when they were growing organisms. Some of these are of great size, one specimen, which can be distinguished in the illustration on Plate XXIX., was six feet in height. The marl represents the reef débris which is found between the growing or dead coral heads of living reefs, and is often accompanied by shells of Mollusks, Echini, etc. In greatly altered reef rock the coral heads and marls become consolidated into firm semi-crystalline white limestones, marked by irregularity of texture and numerous minute cavities representing the original interspaces of the coral skeleton, or sometimes representing places from which the coral structure has been dissolved away. These cavities are frequently filled with red clay or sinter.

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[1] Brown, in the Jamaican Reports, page 166, describes a formation similar to that of the Kingston in the parish of St. Elizabeth along the coast from Alligator Pond Bay to Green Bay, in which remains of land shells are found.

This reef rock not only in Jamaica, but in Barbados, Cuba, Panama, Haiti, Guadaloupe, and elsewhere, has an individuality whereby it can usually be distinguished from white limestones of other than reef rock origin. Even when greatly altered by interstital change, true reef rock shows by the traces of reef coral structure and by its rough, cavernous, crystalline, and altogether unhomogenous texture its original nature. Hand specimens showing no coral structure can be selected from a mass of reef rock, for mud, coral débris, molluscan shells, and even shallow water Foraminifera often fill considerable spaces between the coral heads. Such specimens are exceptional occurrences, however, and do not warrant the frequent generalization that great masses of limestone, which show no signs of coralline texture, may often be of coral reef origin. It may be considered reasonably certain that a rock mass in which remains of reef corals are not visible is not coral reef rock.[1]

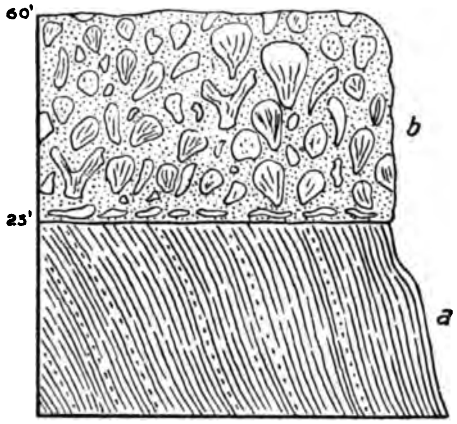

FIGURE 28. Showing Composition of Old Reef, 18 Mile Post, near Hopewell.

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[1] "Coral reef rock is of very varying composition; the coral grows in hummocks separated by more or less narrow spaces which are filled up by coral sand, broken

Generally the Soboruco or old reef rock occurs immediately at the water line, forming an abrupt undermining bluff from five to ten feet high (See Plate XXVIII). In addition to the low level formation, two distinctly higher reefs are sometimes discernible, often a hundred yards or more back of the present beach line, at altitudes of 25 and 70 feet respectively, and constituting distinct formations. Owing to the fact that the old reefs of these three levels are conspicuous bench marks whereby the succession of other formations can be determined, we shall discuss them, where separable, under the names of the Coast Soboruco, Barbican, and Hopewell formations, respectively. Where not separable, or where their exact equivalence is indeterminate, the general term Soboruco will be used. Furthermore, while we believe the sequence of all the formations of the Coast Series is as given in the general table, page 42, for the purpose of discussing the reef made formations together, that order will be temporarily departed from and the latter will now be described.

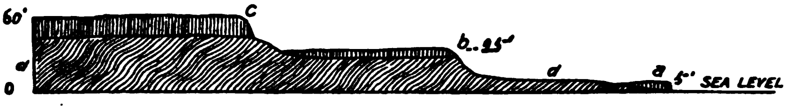

FIGURE 29. Relations of Elevated Reefs near Hopewell.

The best exposures[1] of the Soboruco observed by us were along the road following the coast of the east end of the north side of the island between Port Antonio and Northeast Point, but the sequence of the suc-

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shells, Foraminifera, etc. Microscopic examinations of fragments of limestone broken from coral reefs sometimes show no traces of coral structure. Coral, moreover, is more readily decomposed than shell, sand, or foraminiferal limestones." — Nat. Sci., November, 1897, p. 290.

" *Coral-reef Rock.* — The rock forming the coral platform and other parts of the solid reef is a white limestone, made out of corals and shells. In some parts it contains embedded corals; in others, it is as compact as any Silurian limestone and without a fossil of any kind, unless an occasional shell. The compact non-fossiliferous kinds are formed in the lagoons or sheltered channels; the kinds made of broken corals, on the seashore side, in the face of the waves; those made of corals standing as they grew, in sheltered waters, where the sea has free access. Large portions are a coral and shell conglomerate." — Manual of Geology, by James D. Dana, Fourth Edition, New Haven, Conn., 1895, p. 146.

[1] The distribution of the Soboruco in Jamaica is well shown on the Geological Map accompanying the Jamaican Reports, and in the text it is discussed under the head of the Coast Limestone. The text of the Reports gives only passing attention to these rocks, and does not differentiate them into distinct formations.

cessive reefs is best shown on the west end of the north coast between Montego Bay and Lucea in the parish of Hanover.

Extensive patches of Soboruco border the coast two miles east of Port Antonio. This is made up entirely of large coral heads[1] and superficially consolidated into rough jagged surfaces. It forms a low bluff about ten feet high, which is being undermined by wave action. It extends back from the water only a short distance, and numerous indentations have been cut into it by the sea. There are similar exposures on both sides of Williamsfield Harbor, making the coast line for two or three miles. The horizontal surface of these constitutes a bench against the line of back coast hills, here composed of yellow Pliocene marl. In places in this vicinity the Soboruco is backed by swamps lying between it and the hills. These swamps may have once been lagoons attending the landward side of the Soboruco when it was a reef in the sea. On Plate XXVIII. is an illustration of the Soboruco bench in this vicinity, which shows in the foreground the jagged indurated surfaces of the rock, and in the middle ground and distance the undermining bluff and wave indented incisions. Plate XXIX. shows the composition and structure of the Soboruco, here made up of large individuals of reef making corals. The Soboruco of the east end of the island is unconformable upon the Montpelier white limestones, the Bowden, and the Manchioneal formations.

The straight east coast of the island which extends to Point Morant is reached after passing Northeast Point. At the mouth of Priestman's River a cross section exposing the entire thickness of an elevated reef is seen on both sides of the river for a considerable distance back from the sea, where it forms a vertical scarp some 25 feet in thickness. It overlies the yellow Manchioneal marls in which the present streamway is situated. This exposure of Soboruco is made up of gigantic reef coral heads and its surface constitutes a wide flat bench extending from the sea to the back coast mountains. The top of this old reef is about 70 feet above the sea, an altitude equal to the level of the Hopewell old reef formation on the west side of the north coast, and the greatest height at which any undoubted reef rock is known to occur on the island.

The Priestman's River terrace extends a considerable distance towards Black River. South of the latter as far as Holland Bay its level is continued by a baselevelled plain underlain by the older limestones, probably the Cambridge and Manchioneal formations. Below this level the low coast Soboruco occasionally occurs in spots, as seen between Manchioneal and Hector's River where it stands about 20 feet above the sea and tips nearly all the little points of land projecting into it.

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[1] The species of corals from the localities mentioned are all given in the paleontologic portion of this paper.

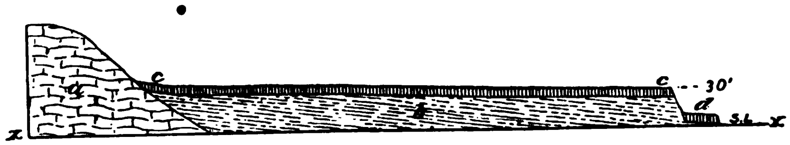

FIGURE 30. Section of Elevated Reef Rock at Mouth of Priestman River.
xx. Streamway of Priestman's River.
d. Later Terrace of Elevated Reef Rock.
c. Older Terrace of Elevated Reef Rock.
b. Manchioneal Beds.
a. Back Coast Mountains of White Limestone.

The east end of the south coast line, between the mouth of Hector's River and Bowden, was not examined, and we cannot from personal knowledge say whether or not the Soboruco exists there. None was seen on the south coast from Bowden to old Port Royal west of Kingston.

Our traverses between Annatto Bay and Falmouth on the north side were mostly through the back coast country, and did not immediately approach the sea except at Port Maria, St. Ann Bay, and between St. Ann Bay and Runaway Bay, but the Jamaican Reports, in the discussions of the parishes of Metcalfe, St. Mary, and St. Ann, under the head of "Coast Limestone," give good descriptions of the Soboruco at many points along this stretch.

One mile west of Port Maria a very small patch of Soboruco abuts against the foot of the great bluff of Richmond beds shown on Plate XXIII. This old reef stands about ten feet above the sea, and is cut by waves into detached islets, specimens of which are shown on Plates XXX. and XXXI. The material consists of coral heads, of which some were over three feet in length and had to be blasted away by the road builders.

Between St. Ann Bay and Runaway Bay, nine miles to the west of Port Maria, there is a narrow ribbon of coast plain abutting against a background of the flint-bearing Montpelier beds. The lowest Soboruco outcrops at several places along this road, and is apparently synchronous with the Falmouth formation described on a later page, which here sometimes replaces or grades into the reef rock. Patches of Soboruco tip the points of land to the east and west of Runaway Bay (not noted on the official geologic map), and nowhere does it stand over ten feet above the sea or extend back from it over a few yards.

Near Orange Bay east of Port Maria the railway cuts through a mass of old Soboruco some 25 feet in thickness, which is very much consolidated and crystallized, and resembles more nearly the true white limestones than any other exposure of old reef rock seen on the island. It is made up almost entirely of coral heads. Three miles west of St. Margaret Bay there is a bluff of very old looking Soboruco, standing 35 feet above the sea. Between St. Ann Bay and a point within four miles of Montego Bay, the coast plain for the most part consists of the beds of white marl elsewhere described as the Falmouth formation, although occasional patches of Soboruco are seen immediately bordering the sea, standing about five feet above mean tide level.

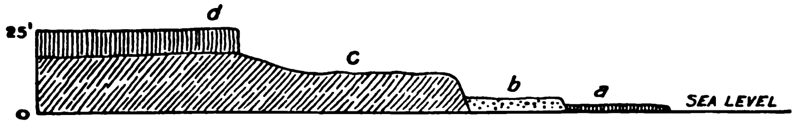

FIGURE 31. Elevated Reefs, Mile Post 97, Coast Road, East of Montego Bay.
a. Coast Reef. *c.* Bench of Vertical Richmond Shales.
b. Grand Plain. *d.* Old Reef.

About four miles east of Montego Bay there is a fine exposure showing two distinct terraces of Soboruco. The older of these is 25 feet high and corresponds to the Barbican terrace. This is a considerable distance from the shore bluffs toward the sea; the newer reef merely tips the coast at the sea margin, and is only five feet above it. There are several patches of the lowest Soboruco at the town of Montego Bay and on the western portion of the bay before reaching Round Hill Point in the vicinity of the mouth of Great River. Round Hill Point is an abrupt escarpment about 100 feet high. The background is composed of Montpelier white limestone. Against this, at a lower level are other beds possibly equivalent to the Manchioneal formation, while at the foot of the bluff is a small patch of Soboruco as shown in Figure 32.

In Hanover Parish, between the mouth of Flint River, twelve miles west of Montego Bay, and Lucea Harbor, are the best and most instructive exposures of Soboruco to be seen around the island. These consist of three distinct formations occurring at 70, 25, and 5 feet above sea level. The highest and oldest of these is well exposed at the 18 Mile Post from Montego Bay, near Hopewell (see Figure 28) along the stretch of coast between Mosquito Cove and the east point of Lucea Harbor. Here the highway is located upon a narrow strip of low coast plain, following an inland bluff whose base, to a height of 30 feet, is composed of the black shales of the Richmond beds, which stand almost vertically. Above these is a firm scarp rock of old Soboruco 30 feet thick. This Soboruco is made up of gigantic coral heads of many species, as shown on Plate XXIX. The heads are embedded in a matrix of dirty white and yellow marl, and have been so altered by induration and crystallization that they could be broken by the hammer only with great difficulty. The summit of this reef constitutes a level which is visible for several miles. It corresponds in altitude, thickness, and lithologic character with that elsewhere noted at the mouth of Priestman River near Northeast Point in Portland. This Soboruco is the oldest not only by occurrence, but also in appearance; the coral heads are more consolidated and crystallized, and the embedding material is of a yellow color indicative of long oxidation. The unconformable contact of this old reef with the almost vertical Richmond beds is clearly shown in a bluff over 100 yards in length.

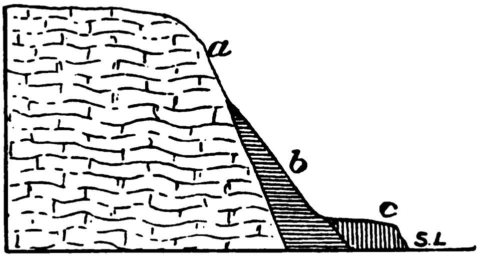

FIGURE 32. Bluff, West Bank of Mouth of Great River, near Round Hill Point, Montego Bay.

a. Back coast country of old White Limestone.
b. Yellow Marls allied to Manchioneal Formation.
c. Soboruco near sea level.

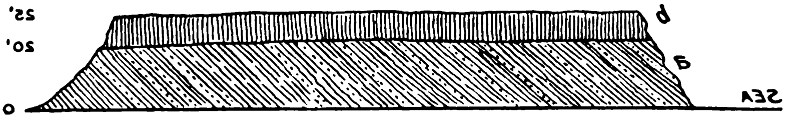

FIGURE 33. Old Reef unconformable on Old Eocene Clays near Barbican.

a. Subvertical Richmond Formation.
b. Reef Rock.

Another type of old reef rock is seen near Barbican, some three miles east of the foregoing locality, in an excellent exposure. This is similarly situated relative to the road and sea as the Hopewell Reef, and likewise occurs unconformably upon the black Richmond shales, here having a dip of 45 degrees. This old reef, which we term the Barbican formation, is only three feet in thickness, and is largely composed of a species of coral having an elongated cylindrical or club-like form, and a concentric arrangement of its layers. Figures 34, 35, and 36 show the occurrence of the Barbican reef and its relations to the adjacent topography.

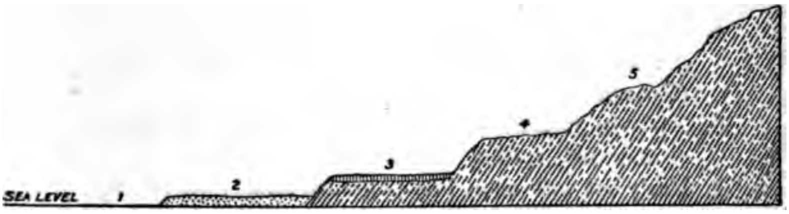

FIGURE 34. Elevated Reef and Profile near Barbican.

1. Caribbean Sea.
2. Low coast plain five feet above sea, and 200 yards wide.
3. The Barbican Reef.
4. A bench 70 feet above sea, occupying the level of the Hopewell Reef.
5. Back coast country, largely composed of the vertically tilted Richmond Beds of the Blue Mountain Series.

The juxtaposition of the Hopewell and Barbican reefs and the lowest coast terrace relative to each other are well shown in the topography adjacent to Mile Post 19, displaying three distinct benches or terraces against the mountainous back coast country.

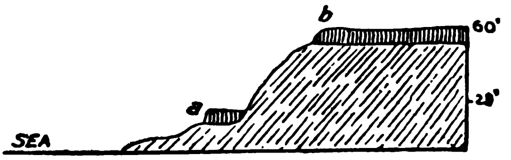

FIGURE 35. Relation of Barbican and Older Reef near Mosquito Cove.

Immediately at Barbican the Barbican terrace, or twenty-five foot level, approaches close to the sea and overlies a fossiliferous sinter or marl which is exposed at the foot of the escarpment, and which is full of molluscan fossils resembling those of the Falmouth formation.

This marl, in turn, is tipped at the sea by the lower Soboruco. A general section of the Barbican and lower rocks at this point is as follows.[1]

	Feet.
5. Coast Soboruco, made up of coral heads largely Meandrina, occurring at and four feet above sea level . .	4
(Unconformity).	
4. Coarse marl with shells and corals, irregularly indurated and cemented. Forms base of bluff . . .	6
(Unconformity.)	
3. Barbican formation. Soboruco of coral heads, firmly cemented, resting unconformably upon 1	8
2. Marly bed with many broken branch corals (reef débris) which generally underlies the above in this region .	4
(Unconformity.)	
1. Richmond beds, forming the fundamental rocks upon which all of the above are deposited. Only partially exposed.	

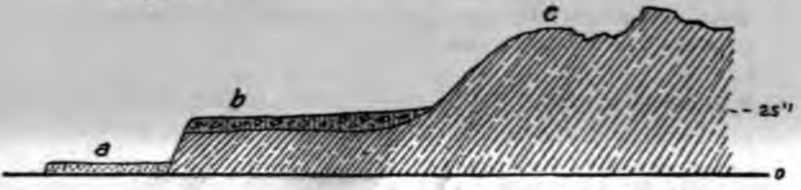

FIGURE 26. The Barbican Reef at Barbican.
a. Coast Marl.
b. Barbican Reef.
c. Richmond Beds.

From Mile Post 19 to Mile Post 21½ the coast topography shows only two of the benches, the immediate coast plain and the Barbican or twenty-five foot terrace, which projects out from the back coast hills. At twenty-one and a half miles from Port Antonio the seventy foot or Hopewell reef terrace again appears as a prominent feature in the coast topography.

Lucea Harbor has the shape of an elongated mule shoe and is a bight cut out of the land mass, here principally made up of the Richmond shales. The points of the harbor adjacent to the sea are tipped with the low coast Soboruco.

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[1] In lithologic characters this agrees in the main with that given of the locality by Brown on page 248 of the Jamaican Reports.

The foregoing descriptions of the Soboruco practically include all localities studied by us, except the coast adjacent to Savanna-la-Mar. The observations include points around the entire perimeter of the island except the extreme west coast and the south coast west of Kingston.

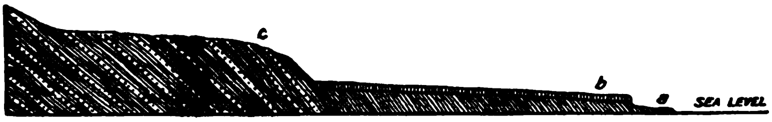

FIGURE 87. Cross Section, West Side of Lucea Harbor.
a. Soboruco.
b. Elevated Reef.
c. Folded Richmond Beds.

Those portions of the coast not seen by us have been sufficiently described and mapped by the official surveyors to show that the Soboruco occurs at many points in them. From Brown's description of Westmoreland[1] it is evident that the ten foot or coast Soboruco, and the twenty-five foot or Barbican Soboruco, are each represented there at a different locality, the former between Scott Cove and White Hill Point, and east of Homer Cove, and the latter at South Negril Cliff. The same author[2] describes, in a general way, the Soboruco in St. Elizabeth, where it forms low cliffs 15 or 20 feet high and rests upon the "White Limestone." He ascribes it to a Post-Pliocene age. No definite mention is made of this formation along the coasts of Manchester or Clarendon (Vere) by the Jamaican geologists, although it is placed upon the map by them.

CONCLUSIONS CONCERNING THE ELEVATED REEFS AND THE HISTORY OF REEF BUILDING CORALS IN THE JAMAICAN SEQUENCE.

The old reefs grew upon marginal benches or terraces, which previous to their submergence were probably wave-cut constructional or gradational plains like those now seen upon the land configuration. As they successively rose during subsequent elevation to within 20 fathoms or less, the zone of coral growth, they were occupied by the polyps which constructed the reef which has since been elevated into land.

That Jamaica was once a more extensive land than now, with benched and terraced margins which were submerged by subsidence, is shown not only by the adjacent submarine configuration but by the elevated reefs themselves, such as that at Barbican, which can be seen to be clearly deposited upon a surface horizontally eroded across the vertical structure of the old Blue Mountain Series. Similar submerged plains are now occupied by the growing reefs around the island. That these elevated reefs were formed on former land surfaces which had been submerged and were in the process of emerging, is attested by every topographic feature. The streams have cut continuously downward through steadily rising old reefs, leaving no evidence of alternating periods of drowning between them, such as veneerings of later sea deposits across them.

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[1] Jamaican Reports, p. 228.

[2] *Op cit.*, pp. 208, 209.

Our studies of the Oceanic Series have shown that true reef building corals do not occur in the great mass of white limestone composing the structure of the back coast country of Jamaica, or at altitudes greater than 70 feet. Our paleontologic discussion also shows that the true modern reef building coral species first appear doubtfully in the Bowden beds, then sparingly in the Manchioneal formation, along the coast between Mulatto Bay and Manchioneal and near Round Point, Hanover. These and all succeeding beds containing reef coral occur only immediately adjacent to the present seacoast and unconformably against the pre-eroded perimeter of the main area of the island.

These reefs are laid down on various formations from the Richmond shale to the Manchioneal beds, respectively. On the north coast of the island they are seen in contact with the Richmond, Montpelier, Moneague, and Manchioneal formations, while upon the south side they lie upon the Cobre, Bowden, and Montpelier.

In general, the old reef rock of Jamaica consists of three distinct formations occurring at three levels, 70, 25, and 10 feet (or less) respectively. From the persistency of these three levels on the north, east, and southwest end of the island, it is evident that their present position above the water is due to continuous epeirogenic elevation after the present outlines of the island had been chiefly defined.

MISCELLANEOUS COASTAL FORMATIONS CONTEMPORANEOUS IN ORIGIN WITH THE ELEVATED REEFS.

The present land margin is not continuously fringed by growing reefs, but they occur in interrupted patches, alternating here and there with strips of different kinds of bottom, such as alluvial deposits opposite the mouths of rivers, shell sand, or lagoon mud. Similar conditions prevailed during the time of the creation of the old reefs, and hence we find with them many diverse formations of contemporaneous origin, some of which will now be described.

The Falmouth Formation.

On the coast of Trelawney, Hanover, and Westmoreland, immediately adjacent to the sea and seldom rising more than 15 feet above it, there is a formation of white chalky marl, usually friable but frequently indurated. In this are preserved numerous mollusks and fragments of reef building corals. The fossils retain all the nacre and other characteristics of living species, and have been pronounced by Dall to be of Post-Pliocene age. This formation indurates in places into a close textured chalky white limestone, superficially indistinguishable from many beds of the Oceanic Series, but on close examination it can always be distinguished by the numerous fossils, as well as by its entirely different microscopic structure, which shows it to be old beach marl. Among the numerous fossils are many species still living in the adjacent waters, including Strombidæ and a small Bulla, the latter being the same which is common in the limestone of Yucatan, the island of Barbuda, and other localities in the West Indies. This formation is important, because it has wide occurrence throughout Tropical America, and, when properly studied, will assist in general correlation.

An outcrop of white limestone, similar to the Falmouth formation, occurs at Hospital Point, north of Montego Bay. This contains the remains of large Strombidæ, and other well known species living in the present sea. Fragments of coral heads of the reef building species are quite common in this material. Good collections of the fossils of the Falmouth formation were also made near Landovary about seven miles west of St. Ann. These consisted of many molluscan species associated with single heads of reef coral. The formation here is so indurated that it might well be termed white limestone, and easily confused with the white limestones of the Oceanic Series. In St. George and Metcalfe the formation consists of almost horizontal beds of white marl with the mangrove oyster, between Canewood and Spanish River, and from Low Layton to Retreat and Savanna Point.

The Falmouth formation was nowhere seen to be more than half a mile wide on the north coast, but on the southern coast of Westmoreland, back of Savanna-la-Mar, it indents the country for a considerable distance. Its occurrence at this locality has been well described by Brown under the name of "White Marl"[1] and "Bulla Limestone."[2] Here it consists chiefly of a soft white lime marl, usually bedded, and having some layers more eroded than others. Back from the coast the

[1] Jamaican Reports, pp. 229, 230.

[2] Ibid., pp. 228, 229.

fossil remains are few, but adjacent to it they abound and are well preserved. Owing to the fact that the formation here lies comformably upon the Montpelier beds, and that they have strong lithologic resemblance to it, it is difficult always to distinguish them. At Little Bay the fossils especially abound, and include numerous teeth of sharks. Thanks to Professor Duerden, of the Institute of Jamaica, we have Brown's collections from these localities in Washington, and they correspond perfectly with those made west of Falmouth on the north coast.

The marls and limestones of the Falmouth formation are consolidated sea mud, consisting of material exactly similar to the so called shell and coral sand which frequently makes the present sea border around Jamaica. It is entirely distinct from true reef rock, for it is not original reef material at all, although much of it may have been derived from reef débris. It is littoral organic oceanic débris which has been deposited around the perimeter of the island, along borders free from land sediment or in lagoons between the reefs and the land.

In age the Falmouth formation is newer than the older or highest elevated reefs, and probably synchronous with the middle and lower Soboruco; hence it must be assigned, like them, to the Pleistocene or a later epoch.

Miscellaneous Pleistocene and Recent Formations. — In addition to the old Kingston formation and kindred deposits in the interior valleys, there are many aggradational formations of more recent origin, around the margin of the island, occurring as alluvial streamway deposits disgorged along the coast, or gravel beds resulting from the undermining of the Richmond formation where it approaches the sea. The gravel of this material is mostly of the Blue Mountain Series, but it also contains pieces of various other formations.

The Montego Formation.

At numerous places around Jamaica are patches of swamp or morass adjacent to the sea and almost level with it. These are usually composed of alluvium brought down by the rivers, and are more recent than the Kingston formation previously described. They are well shown along the immediate coast at the mouth of Montego and Retirement Rivers south of Montego Bay town and thence around the coast, proceeding eastward, as follows: near Montego Bay town and Umbrella Point, St. James Parish; Half-Moon Bay, Trelawney Parish; Palmetto Point, district of St. George in Portland Parish; between Plantain

Garden River and the coast south of Morant Point; the Salt Ponds near Yallahs Point; bordering Hunt Bay between Cobre River and Apostle's Battery on the west side of Kingston Harbor; from Cabiretto Point to West Harbor on the east coast of the district of Vere, Clarendon Parish; along the south coast of Vere and Manchester from Portland Ridge to Cut River; between Star Cut Bay and Scott Cove extending inland adjacent to Black River on the southwest coast of St. Elizabeth Parish; from Bluefields Bay to St. John Point in Savanna-la-Mar; along the truncated west coast of the island between South Negril Point in Westmoreland Parish to Orange Bay in Hanover Parish, and around Green Island harbor, Hanover Parish.

Where these morasses extend a few miles inland up the rivers they occupy eroded indentations cut out of the lower Soboruco or Liguanea levels, as is especially well shown at Montego Bay, Long Bay, and the mouth of Black, Milk, Cobre, Plantain Garden, and Green Island Rivers. In one or two places, as along the north coast between Palmetto Bay and Buff Bay, the Salt Ponds, and elsewhere their configuration strongly suggests that they were originally lagoons on the interior side of barrier reefs.

These morasses are most extensive at the mouth of Black River, St. Elizabeth, and at Long Bay, west end; and near Morant Point, east end, where they extend back from the sea for two or more miles. Elsewhere they are elongated narrow strips less than a half mile in width and occur between the sea and the back coast border.

These formations occur relatively to the Manchioneal, Hopewell, and Barbican formations of the Coastal Series, in the same manner that the Coastal Series, as a whole, occurs relative to the rest of Jamaica, i. e. they are deposited in eroded bights and on eroded plains cut out of the preceding formations.

The Bogue Island Formation.

The last to be described, but by no means the least interesting formation of the Jamaican sequence, is that which composes a number of atoll-like islands in Montego Bay about one mile west of the city. These lie just off shore in the greatest indentation of the bay. Looked down upon from the elevated back coast hills, as seen in the illustration (Plate XX.), these islands appear to be a group of typical coral atolls, consisting of small circular belts of land enclosing interior lagoons. When visited and closely inspected they are found not to be of this character.

There are eight of these islands, none of which exceeds a few acres in area, and most of them are perfectly circular in outline. Five of the circular islands and one of quadrangular outline enclose interior lagoons. Until one puts foot upon them they appear to stand eight or ten feet above the sea, owing to the dense growth of mangrove trees which rise to that height. Then it is seen that several of them show no land whatever above the water, but consist of circular patches of mangrove trees growing out of the sea. Others visited by us consist of a low ring of wind-blown shell and coral sand, nowhere rising over three feet above the sea. A shallow living reef underlies the whole area of the sea where these pseudo-atolls occur, and constitutes the platform from which they rise. A typical island presents the following cross section, Figure 38.

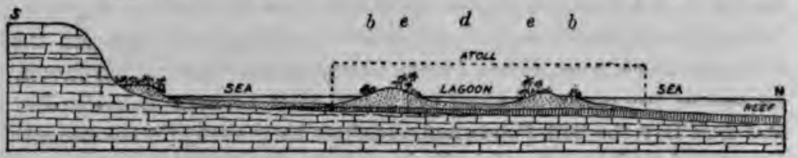

FIGURE 38. Cross Section of the Pseudo Atolls at Montego Bay.
d. Interior Lagoon of brown colored brackish swamp water.
e. Land composed of coral sand and shell, covered by palms and cocoanut trees.
b. A ring of mangrove bushes growing from the water around the island.
s. The floor of the sea is a living coral reef, with many Algæ, Echinoderms, Mollusks, etc. The top of this reef is about two feet below the surface.

We can offer only one hypothesis to explain these islets, and that is as follows. As described by A. Agassiz[1] in the instance of the Florida keys, "young mangrove plants drift in immense quantities upon the submerged flats which reach nearly to the surface of the sea or become awash." These grow up in clumps like some of the small islands now seen. By wind and wave action the reef débris is accumulated around the roots of these trees, gradually embedding them and ultimately rising above the water as land. The circlet of land thus made cuts off the older mangroves from the sea water. The older and original mangroves, now sand clogged, become the interior of the islet, and decay and die for want of access to salt water. Rain charged with carbonic gas from the decaying vegetation then compacts and dissolves the shell sand, and converts the central portion into lagoons around which newer land continues to be made by wave and wind. Meanwhile the new growth flourishes adjacent to the salt water.

[1] Three Cruises of the Blake, Vol. I. pp. 52, 53.

In addition to the true islets there is a circular head projecting from the land as a peninsula, the narrow neck of which, if severed, would leave an islet of the kind we have described. This and the land immediately back of the island is a mangrove covered morass of the type we have just described as the Montego formation.

Nowhere can so grand a combination of erosive and constructional processes or the successive formations of the Coastal Series, as a whole, and their relations to the older formations of the island, be seen in a single view as at Montego Bay. This is a great indentation into the coast, the back country of which is composed of beautiful hills covered with tropical upland vegetation, rising in a series of grand terraces to a height of 1,000 feet or more, as shown in Figure 6 and on Plate XX. This plain is composed of the following formations of the Coastal Series: the Manchioneal beds, the twenty-five foot level or middle old reef, the low level Soboruco, and the Montego formation, while the Bogue Island formation barely appears above the waters of the bay. In the shallow bay fringing reefs are growing, and Mollusks, Echinoderms, and other sea shells are dying and contributing shell débris, which near the shore is mingling with the aggradational alluvium brought down by the rivers. Elsewhere it forms great deposits of purest calcareous sand.

The Montpelier formation, with its contorted beds of chalk and flints, forms the back coast hills in which this scene is set, and against which the various other formations lie in unconformable contact. Fragments of the yellow marls allied to the Manchioneal formation can be seen against this on the west point of the harbor between the mouth of Great River and Round Hill Point. The old Soboruco, now converted into a white limestone rising fifty feet or more, constitutes the opposing northeast point of the bay. The railway station back of the town is upon a low level plain made up of shell bearing marls equivalent to the Falmouth formation, while the low coast Soboruco borders the sea at the city and Round Hill Point. The Montego formation occupies a still lower plain, almost or at sea level, cut out of the low Soboruco and Falmouth formation, as seen in the morasses south of the city. The indentation comprising the bay and coastal plain was cut by the combined forces of erosion baselevelling the land, and wave action indenting the shore, probably in late Pliocene time; afterwards this plain was submerged, veneered by deposited sediment from the land, and inhabited by growing reefs. Later elevation brought the interior margin of the bay above the water, constituting the present low land extending between the sea line and the back coast hills, while coral reefs continued to grow upon the shallow portion which remained submerged. These processes are more fully discussed in the chapter dealing with the geological history of the island.

THE IGNEOUS ROCKS OF JAMAICA.

The following discussion of the igneous rocks of Jamaica is based upon our field observations, including a study of the principal localities enumerated in the Jamaican Reports and many new exposures opened to view by the construction of the Port Antonio Railway; the microscopic studies of specimens collected by us, and of those collections of the Jamaican Survey which were loaned us by the Museum of the Institute of Jamaica, are by Whitman Cross. No microscopic studies of Jamaican igneous rocks have hitherto been made, so far as we are aware, nor has any systematic discussion of the rocks been attempted, although details of occurrence are given in the Jamaican Reports.

Barrett, speaking of the porphyry in St. Thomas,[1] said in an early paper that it is "evident that the igneous rocks (porphyries) forming the base of this series, and interstratified with some of the shales and conglomerates, were erupted prior to the deposition of the Cretaceous limestones, and at intervals of time sufficient for the formation of interbedded aqueous strata." This assertion may have led the geologists in England who wrote the Appendix of the Jamaican Reports to believe these rocks fundamental, but Barrett himself, as well as Sawkins, in their later reports on the eastern parishes of Jamaica, clearly show that the rocks are intrusive and not fundamental. (See description of Blue Mountain Series on pp. 51–53, also pp. 111, 112, of this work.)

Sir Roderick Murchison has said that the igneous rocks "are for the most part either of the Miocene age, or posterior to that era; some of them, as is well known, having been indeed recently erupted."[2] One would also infer a pre-existing foundation of igneous rocks beneath the sedimentary section of Jamaica from the columnar section on page 341 of the Jamaican Reports, and the unqualified statement by Etheridge, page 306 of the same Reports, that "the conglomerate and Cretaceous series rest upon Granitic and Porphyritic rocks," and from numerous references to granites throughout the body of the Report. Careful study of the individual reports upon the different parishes re-

[1] Quart. Jour. Geol. Soc. London, 1860, Vol. XVI. p. 326.

[2] Jamaican Reports, Introduction, p. iv.

veals the fact that the rocks alluded to are clearly intrusive into the overlying sedimentary section. Our personal observations enable us to say positively that, while the oldest known rocks of the island are undoubtedly rolled eruptive volcanic débris, no fundamental massifs of plutonic crystalline rocks, granite or other kind, are known to occur as a previously formed basement or axis to the sedimentary section of Jamaica. On the other hand, these rocks, by occurrence, are all eruptive and intrusive, and in age are contemporaneous in origin with the sedimentary rocks.

The igneous rocks can be classified by age, occurrence, and mineralogic composition into three distinct categories, as follows: —

I. The andesitic (mostly hornblende) boulders, pebbles, and tuffs of the Blue Mountain Series, of eruptive origin from unknown vents, contemporaneously deposited with the Cretaceous sediments of the lower beds and occurring as rolled and worked over material in the Richmond beds of the upper part of that series.

II. The hornblende diorite and granitoid porphyries of the five eastern parishes of the island, constituting dikes and masses, or laccoliths, intruded through the rocks of the Blue Mountain Series and into the Montpelier formation of the Oceanic Series. These rocks are of Mid-Tertiary age.

III. Eruptive amygdaloidal basalts of the Low Layton stock or volcanic neck in the north coast of Portland. Mid-Tertiary.

I. *The Boulder Material of the Blue Mountain Series.* — In the general description of the Blue Mountain Series we have noted the predominance of conglomerates, boulders, pebbles, and tuffs, composed of rolled volcanic rock, and the fact that the accompanying shales and sandstones are made up almost, if not entirely, of this material, which has undergone aqueous trituration. This boulder material is the oldest formation exposed on the island, and it has survived by rolling and redeposition through all succeeding epochs, being especially conspicuous in the Richmond, Bowden, Kingston, and modern aggradational deposits.

Particular attention was paid by us to the study of the composition and origin of this material. Specimens from what are apparently the oldest formation of the island, — the Frankenfield conglomerates of the Rio Minho section of Clarendon, — as determined petrographically by Cross, show that the material is almost exclusively composed of hornblende-andesites and hornblende-andesite tuffs.

Original masses *in situ* from which this boulder material could have derived, are nowhere known to be exposed on the island, and hence its exact mode of origin is questionable. From its vast quantities, — probably aggregating 3,000 feet in thickness, — its eruptive nature, its size and freedom from foreign material, and the occasional colonies of Cretaceous species which found temporary foothold during its deposition, there can be no doubt but it represents the piled up débris of a great volcanic vent or vents which rose from the waters of the Caribbean Sea in Cretaceous time, approximately where the island of Jamaica now stands, and constituted a nucleal land around which all subsequent terrigenous formations now entering into the structure of the island, and largely made up of its worked over materials, were derived. This fact is one of the most apparent in Jamaican history.

There is some reason to believe that the eruption of the hornblende-andesites continued throughout the epoch recorded in the deposition of the lower part of the Blue Mountain Series up to the time of the commencement of the Richmond formation. The thick beds of tuff alternating with beds of black shale in the Minho beds of the Clarendon section are the last of the undoubtedly volcanic formations in the series.

The more regular stratification and composition of the Richmond beds, although containing vast amounts of water worn volcanic pebbles, indicates that the sedimentary conditions had become more stable and were free from the disturbing effects of volcanic outbreaks. The pebble and conglomerate beds in the Richmond Series are much water worn and distinctly stratified, and occur interbedded with the shales and sandstones, or, when traced out, pass continuously into the latter, which is largely made up of water-rolled grains of igneous rock. These conglomerates are mostly composed of the hornblende-andesite with rolled fragments of Cretaceous limestone. Wall has noted from the Port Maria bluff (see Plate XIII.), from which he collected the Eocene corals described by Duncan, a singular admixture of pebbles composed of "gneiss and crystalline slates, rocks of which no trace either *in situ* or otherwise had hitherto been noticed in the island."[1]

In addition to the hornblende-andesites in the Richmond gravel at Port Maria, Cross found one which may be a dacite. He describes this as follows: —

"No. 52 *a*. — Port Maria. (Pebble in Richmond formation.) A probable surface volcanic rock. It contains many fresh plagioclase crystals with glass inclusions, a few augite prisms, and very little magnetite. The predominant groundmass is cryptocrystalline and may contain a large amount of silica. The rock is to be generally classed with the andesites rich in silica and poor in iron, and thus may be a *dacite*."

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[1] Jamaican Reports, p. 180.

Whether these are exotic or have been derived from more ancient rocks composing the structure of the island and now concealed by later formations, are speculative questions. For the present it is only safe to say that, together with all the other pebbles of the Richmond beds, they are detritus derived from rocks which were originally made in previous geologic epochs, and that there are no indications of contemporaneous volcanic activity during the Richmond epoch.

II. *The Hornblende-diorites, Porphyries, and Granitoid Rocks.* — These rocks are found *in situ* only in the third of the island lying east of a north and south line between Spanishtown and Port Maria in the parishes of St. Andrew, St. Mary, Portland, and St. Thomas, and barely extending into the northeast corner of St. Catherine.

They occur as dikes cutting through the Blue Mountain Series into the Oceanic Series, and as deep-seated interior masses from which such dikes extend upward. These are the "granites," "syenites," "diorites," and "porphyries," in part, of the Jamaican Reports, which contain many excellent detailed descriptions of their occurrence,[1] but nowhere satisfactorily discuss or fully describe them as a whole.

The terms granite, syenite, and porphyry are used interchangeably in the Jamaican Reports for what is practically the same rock or differentiation of the same magma, which being true, most of the rocks under discussion can be reduced to two classes, the first of which is the above mentioned gneiss of porphyritic granitoid rocks, the second, hornblende-diorites. According to Cross, the latter are "all simple normal granular rocks, with much more plagioclase than orthoclase, common green hornblende, and some altered biotite. The quantity of orthoclase and quartz varies in different specimens." In occurrence these rocks cannot well be separated from one another, or at least have not yet been separated. In St. Thomas-in-the-Vale[2] the syenitic, dioritic, and feldspathic porphyries seem to succeed one another to the westward.

While certain rocks are called granites throughout the Jamaican Reports,[3] Sawkins in speaking of these has clearly noted that they differ from the true granites by the absence, abundance, or replacement of one of the constituent minerals. "It must, therefore, be understood that the composition of this rock throughout Jamaica is not always that of quartz, mica, and feldspar, which are the constituents of true granite, but more frequently feldspar, hornblende, and quartz, . . . and throughout the whole series feldspar and hornblende occur more abundantly than quartz."

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[1] They have also been described by De la Beche, but in both cases without microscopic aid.

[2] Jamaican Reports, p. 139.

[3] Ibid., p. 106.

According to the microscopic studies of Cross, the exact nature of these so called "granites," "syenites," and "porphyries" is as follows: —

"Specimen No. 95. — On road to Blue Mountain Peak. A very distinct porphyry of the structural type common in the laccolithic masses and intrusive sheets of probable early Tertiary age in Colorado, and adjacent territory. The rock is near the line between granite-porphyry and quartz-diorite-porphyry, its feldspar crystals are so much decomposed that their character cannot always be made out. Some are plagioclase, some may be orthoclase. I think the rock had hornblende crystals in its fresh state. Now the ferro-magnesian constituents are so far decomposed that they cannot be identified. They were never abundant. The groundmass consists largely of quartz and orthoclase in a fine earthy granular structure."

"Specimen No. 146. — Feldspar Porphyry. District of Port Royal. Salt River. Shelf 6, Institute of Jamaica. Labelled Metamorphic Series. A much altered porphyry with small phenocrysts of orthoclase and plagioclase and a dark silicate now indicated by calcite and chlorite. The outlines of this latter constituent are not sufficiently clear to permit inferences as to whether it was augite or hornblende. Groundmass has some quartz but is mainly orthoclase feldspar."

"Specimen No. 207. — Copper in syenite. District of Metcalfe, Parish of St. Mary. Shelf 7, Institute of Jamaica, 'Granitic Series.' A granite porphyry with much quartz in its irregularly granular groundmass. Pink orthoclase feldspar is the principal component, in irregular large grains seldom of good crystal form, and in the groundmass with quartz. Chlorite replaces a former dark constituent, — probably biotite.

"This granitoid group of rocks, exposed by erosion at many places in the Blue Mountain region, is best developed in a limited area embraced in the district of Port Royal (St. Andrew Parish, St. George, Portland, Metcalfe, St. Mary), and immediately adjacent to the corner of the parishes of St. Andrew, St. Mary, and St. Catherine. All these localities are in a small district of the island near the western half of the Blue Mountain range, occurring in some places over considerable areas. Sometimes these apparently occur beneath all the sedimentary rocks, but usually they can be clearly seen as dikes, stringers, or masses protruding into the overlying rocks, which clearly show their subsequent origin."

Splendid exposures of hornblende diorites are seen along the highway and railroad as they follow the valley of the Rio Doro for five miles, between Williamsfield, St. Catherine, and Newport, St. Mary. Usually these are very weathered and so decomposed that they break down into friable rotten yellow and ferruginous débris, which is cut away with spades by the road makers, but maintains a porphyritic structure to the last. Just north of the new iron bridge the railway cuttings exhibit for the first time exposures of the material in a fresh and comparatively unaltered state, specimens of which are the basis of Cross's description. This material everywhere has a vertical arrangement, as if it had been thrust up from below. On the south side of the area in St. Catherine it is overlain by the Cambridge formation, while to the north near Richmond, St. Mary, it is covered by the Richmond beds.

The intrusive nature of these rocks, both dioritic and granitoid, is seen everywhere throughout the districts mentioned. The dioritic dikes abound in the same localities east of Clarendon, traversing the whole of the Blue Mountain Series.[1] In fact, wherever the rocks of this series occur east of Clarendon, the intrusions can be seen pushed through the strata and altering the adjacent rocks. But few of these dikes are of narrow even sided proportions, but are mostly broad and ragged, and often 300 feet or more thick.

In Metcalfe the granitoids underlie and protrude into the conglomerates of the Minho beds. In the Plantain Garden region according to Barrett,[2] these are immediately below the Hippurite bearing Cretaceous limestone; in Portland, *vide* Barrett,[3] south of Port Antonio, they underlie the same limestone, which has been highly altered and metamorphosed along the line of contact. Between Guava Ridge and Content they have pushed up into the shale beds of the Blue Mountain Series,[4] as seen by us; in St. Andrew they clearly protrude through the various rocks of the Blue Mountain Series.[5] South of Port Antonio they have apparently elevated all the rocks of the Blue Mountain Series and the Montpelier beds of the Oceanic Series;[6] in St. Catherine they occur between the top of the Blue Mountain conglomerates and the base of the white limestones, and abut against and metamorphose the latter in the northeast corner of the parish;[1] according to Lennox,[2] "the granite in the adjacent regions of St. Thomas-in-the-Vale is certainly posterior in date to the White Limestone."

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[1] Jamaican Reports, pp. 65, 71, 93, 95, 112, 122, 144, 188.

[2] Ibid., p. 308.

[3] Ibid., p. 75.

[4] Ibid., p. 97.

[5] Ibid., p. 105.

[6] Ibid., p. 86.

The numerous observations of the Jamaican geologists, verified by our own, justify the opinion expressed by most of them that these so called granites are of Tertiary age,[3] and we think at least of a date later than the Montpelier epoch, — a conclusion borne out not only by the facts presented but also by the absence of the débris of these rocks in the conglomerates so abundant in the preceding formations.

From the fact that the composition of these rocks shows them all to be of deep seated origin, and from their occurrence as masses beneath various formations into which they send dikes and sills, and owing to the fact that no evidence exists that they were ever protruded to the surface, we believe they represent the various phenomena of a great laccolith which in Tertiary (Middle Oligocene) time was protruded upward into the then existing formations of the Jamaican sequence. Furthermore, it is our opinion that the intrusion of these rocks was associated with the elevation of the island, and the progressive shallowing so evident in the ascending sequence of the White Limestones, whereby they changed from the deep sea foraminiferal deposits of the Montpelier beds into more shallow limestones, and, finally, into the land areas which existed at the time of the peripheral deposition of the Bowden Oligocene.

III. *The Low Layton Eruptives.* — At only one locality on the island is there supposed evidence of the occurrence of true eruptive rocks *in situ*, or of igneous rocks of later age than those already described. This is at the Black Hill near Low Layton, adjacent to Savanna Point, on the north coast, between Bluff Bay and Hope Bay, in the parish of Portland. This is a ridge extending from the seacoast near Retreat to near Low Layton, accompanied by one or two outliers and reaching an altitude of 700 feet. Here it has been asserted there is a neck or stock, or possibly the remains of old lava flows of what was once apparently a true volcano protruding through the Pliocene limestones. This hill has undergone great denudation.

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[1] Jamaican Reports, p. 146.

[2] Ibid., p. 147.

[3] Barrett (in the Jamaican Reports, p. 81) states: "The porphyry has altered the Cretaceous and Eocene rocks, and it is contemporaneous with the lower part of the White limestone series, so that it was erupted after the deposition of the Eocene (Black Shale) series, but before the formation of the Pliocene (White limestone ?) strata; its geological age is therefore Miocene" (Oligocene). See also pages 146, 182, of same report for like opinions of other writers.

This material and the accompanying phenomena of the outcrop have been described by Brown,[1] as follows: —

"The kinds of rock of which it is composed are amygdaloid and a pasty-looking brown agglomerate. The amygdaloid is composed of a hard blackish base or matrix containing kernels of carbonate of lime, and the agglomerate is made up of blocks of this amygdaloid embedded in a reddish iron stained material, which is extremely siliceous. Down the slope from the top of the volcanic ridge to the valley the bare patches of brownish lava, with blocks of amygdaloid sticking in them, evidently indicate the direction of the old lava flows. Masses of rock jut out from the face of the hill, which have all the appearance of huge rubble walls cemented with lime; on examination they are found to consist of large blocks of lava intermingled with white limestone. In these the limestone has become cherty."

Two hand specimens of this rock petrographically studied by Cross were determined by him as follows: —

No. 143. — District of St. George. Low Layton. Basalt. (Plagioclastic.) Fresh typical basalt, holocrystalline, vesicles filled with crystalline calcite. No Globigerina.

No. 141. — Low Layton. Dense reddish groundmass obscured by ferritic material and containing olivine (altered), plagioclase, and augite. Vesicles partly filled with very distinct Globigerina.

Since the date of Brown's observations, the Jamaican Railway has tunnelled through the base of the hill, but the only new data it contributes is the fact that the igneous rocks are encountered 700 feet below the summit of the hill, and shows the latter to be of the nature of a volcanic neck rather than an entirely superficial lava flow.

It is also probably older than the Post-Pliocene to which Brown assigned it. Our reasons for the latter conclusions are as follows. The fact that the débris of the basalt is intermingled with the flint bearing white limestone of Vicksburg age (supposed to be Miocene or later by the Jamaican Geological Survey) does not necessarily prove the Post-Eocene age of the basalt. On the contrary, the presence of the characteristic fossils and chalk of the Montpelier limestone in the scoriaceous cavities of the basalt clearly shows that this limestone was deposited contemporaneously with or after the basalt. The yellow calcareous marls described as lying almost horizontally upon portions of the volcano were tentatively considered at the time of our examination to be the Buff

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[1] Jamaican Reports, p. 120. These rocks were also mentioned by De la Beche, *op. cit.*, pp. 185–187.

Bay (Bowden) formation of late Oligocene age. If this hypothesis is true, then the Low Layton rocks were made before or during the Montpelier epoch and previous to the Bowden Oligocene. Further research is necessary to determine this question finally. In any event, the Low Layton "volcano" represents the latest of the igneous rocks in Jamaican history, and nowhere are there evidences of further vulcanism.

Metamorphic Influences of the Tertiary Intrusives. — The intrusion of these granitoid and dioritic rocks into the strata of the Blue Mountain Series and lower part of the Oceanic Series has locally produced extensive metamorphism of the adjacent rocks, baking the shales into hard friable slates, and indurating the Cretaceous limestones. According to Sawkins,[1] even the white limestone in St. Catherine "is so completely metamorphosed as to be entirely different from the ordinary type." The Jamaican geologists have also asserted that in places the shales have been converted into porphyries[2] and the limestones into serpentines. We are not prepared to affirm or deny these assertions.[3]

In localities where the metamorphism and alteration of the Blue Mountain Series has been extensive, the Jamaican geologists have referred to the rocks under the formation name of the "Metamorphosed Series," which they have distinctly defined[4] as "conglomerates, shales, sands, and limestones, that have undergone various changes by the intrusion of igneous dikes." It is evident from their descriptions, as previously noted, that they did not intend to give these rocks a definite place in the Jamaican section otherwise than contemporaneous with the conglomerates, shales, and Cretaceous limestones of the Blue Mountain Series in general; but the editors of the final table in the Reports,[5] and of the general geologic map and sections, have given this series a definite position in the geologic section below the "Hippurite limestone" and above the "granite and syenite," thereby creating the erroneous impression that the metamorphosed beds constitute a distinct formation.

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[1] Jamaican Reports, p. 147.

[2] Ibid., pp. 62, 188.

[3] Ibid., p. 62.

[4] Ibid., p. 41. See also p. 105 for a similar definition.

[5] Ibid., p. 341.

PART III.

Paleontology of the Jamaican Sequence.

The entire Jamaican section contains many unfossiliferous horizons. In other words, while there are a few zones[1] where abundant macroscopic fossils occur in abundance, a large part of the 10,000 feet of strata are non-fossiliferous. The lower Blue Mountain Series are mostly without fossils because of the disturbed conditions during their deposition. The upper portion of the Series is likewise mostly barren, owing to the turbulence of the muddy waters in which it was laid down. The deep water Tertiary white limestones, although largely composed of microcopic organisms, contain vast thicknesses of rock with no macroscopic organic remains. This is due to the fact that these limestones were deposited at great depths, where fossil making forms other than Radiolaria were few in number, and the calcareous skeletons of such as did exist were dissolved by deep sea waters.

On the other hand, the many changes of the character of the habitat, such as the introduction into the sea of the material of the Cretaceous volcanic outbreaks and changes of level in the later epochs, have interrupted the continuous existence of such littoral faunas as leave the most abundant remains and which from time to time may have secured foothold around the island prior to late Oligocene time. Thus it is that the few colonies of Upper Cretaceous life which obtained ephemeral existence around the margins of the island were deficient in species; the Cambridge forms, a little more diversified, and the Bowden and later species are numerous, as the surrounding seas afforded more constant and favorable conditions for the life of organisms.

The paleontology of Jamaica is difficult to discuss, because many previously known species have been described from miscellaneous collections (made by others than the describers) by naturalists who had not visited the island and had no conception of the stratigraphic sequence, position, association, or exact locality of the forms. Such studies are valuable so far as they result in the correct naming of species, but they are too often accompanied by an unfortnnate duplication of names and conflicting generalizations and deductions. Thus one author referred all the invertebrate faunas of the whole Tertiary and later formations, without a single detail of stratigraphic or geographic location, to the "Miocene,"[1] in which epoch all the fossils of Jamaica and the West Indies in general, with few exceptions,[2] have been placed. In direct conflict with this opinion, another eminent author in the latest paleontologic publication on the island informs us that "No strictly Miocene strata have yet been discriminated in the Antillean region"[3] and refers the group hitherto so called to the upper Oligocene.[4]

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[1] These horizons are marked with an asterisk in the columnar section on page 42.

Another serious class of mistakes due to ignorance of the stratigraphic sequence has been the promulgation of erroneous deductions alleging the occurrence in the Antilles of certain forms entirely out of the age position which they were known to occupy elsewhere, such as European Lower Chalk corals in the Jamaican Miocene,[5] of European Cretaceous corals in the Miocene of Haiti,[6] and the occurrence of Eocene Nummulites and Orbitoides in the Upper Miocene of Trinidad[7] and Miocene of Jamaica.[8] The last mentioned class of errors has had a far reaching influence in general paleontologic literature which will require time and patience to correct.

Another source of confusion was the fact that writers ignored the existence in the island of any Tertiary formations of earlier age than the late Oligocene (Miocene of all authors previous to Dall), a theory which arose from the unfortunate errors of the English writers who confused the Bowden beds of the east near the top with the Yellow Limestone of the western parishes at the base of the Tertiaries

Still another cause of misunderstanding was ignorance of the fact which has been pointed out for the first time in our chapters on the stratigraphic conditions, that the great sea depths which separated the island from the continent during its earlier epochs of history — late Cretaceous and Eo-Tertiary times — constituted effective barriers to migration to the site of the littoral faunas of the continental borders. Owing to these barrier depths only a few or none of the shallow water molluscan species of the adjacent continental borders found habitat in the littoral waters of the island prior to the late Oligocene (Bowden) epoch, when the bottom of the region was sufficiently elevated to permit the migration of shallow water species over wide areas of the tropical seas and to connect the Jamaican littoral fauna with that of the mainland. Forms which abound in the preceding epochs, especially the corals and Foraminifera, are those adapted to wide oceanic migration. These conditions have produced in these earlier faunas a peculiar mixture of genera, comprising oceanic species and a few littoral mollusca which had found accidental foothold and acquired peculiar characters through long isolation, — the whole making a faunal assemblage quite foreign to those known in other typical areas of the world upon which stratigraphic and age classifications have been founded, although retaining generic criteria sufficient for positive age determination. Paleontologists, unaware of these conditions, have naturally failed to obtain in the collections from the island a correct impression of the stratigraphic significance of its fossils.

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[1] Guppy, On the West Indian Tertiary Fossils, Geol. Mag., Decade II. Vol. I. pp. 404–411, London, 1874.

[2] The two species of Eocene corals from Port Maria and the Rudistes.

[3] Dall, Proc. U. S. National Museum, Washington, 1896, Vol. XIX. pp. 303–305.

[4] Ibid., p. 304.

[5] Duncan, Quart. Jour. Geol. Soc. London, Vol. XXI. p. 12, 1865.

[6] Gabb (Geology of Santo Domingo, p. 88) infers that these so called Cretaceous corals in the Haitian "Miocene" are found in gravel of Cretaceous débris.

[7] Proc. Sci. Association of Trinidad, December, 1872. Port of Spain (1873), Geol. Magazine, Decade II. Vol. I. p. 21, 1874, and elsewhere.

[8] Duncan, Quart. Jour. Geol. Soc. London, Vol. XIX. p. 453.

In view of the confused condition of current published conceptions of the paleontology of Jamaica above set forth, it will be impossible in the present chapter to straighten out the confused synonomy of species, a task which must be left to other specialists. Our principal endeavor will be to point out the true stratigraphic position of the material hitherto described, thereby making it of geologic as well as biologic value, and then, by aid of the larger amount of new material collected by us, present some deductions which may be of service to those who in the future undertake the special task of further advancing the paleontology of Jamaica.

CRETACEOUS.

Blue Mountain Series. Lower Division.

From the occasional limestones and marl beds occurring in the vast thickness of tuffs and conglomerates of the lower division of the Blue Mountains, the following fossils have been collected, most of which have a decided Cretaceous facies.

Foraminifera: Rotalia or Pulvinulina[1]; *Orbitoides (?)[2]; Ellipsactina[1]; *Nummulites (?).[2]

Corals: Cladocora jamaicaensis, Vaughan; *Diploria conferticostata,

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[1] Identified by R. M. Bagg. Collected by Robert T. Hill.

[2] Identified by Woodward. Collected by Jamaican Surveys.

Vaughan = D. crassolamellosa, Duncan (non Edward and Haime)[1]; *Multicolumnastræa cyathiformis, (Duncan) = Heliastræa exsculpta, Duncan (non Reuss) and Heliastræa cyathiformis Duncan.[1] Cyathoseris haidingeri, Duncan (non Reuss)[1]; Porites reussiana, Duncan[2]; Leptophyllia agassizi, Vaughan.

Echinodermata: Salenia.

Conchifera: Pteroceras[3]; Nerinæa[3]; Cerithium[3]; Turritella[3]; Actæonella[3]; Natica[3]; Amauropsis (?)[3]; Pleurotomaria (?)[3]; Ostrea[4]; Pecten[5]; Inoceramus[5]; Lithodomus[3]; Pholadomya[3]; Barrettia monolifera, Woodward[6]; Radiolites adherans, *R. rudis, R. cancellatus, R. macroplicatus, R. annulosus, Whitfield[6]; *Caprina jamaicensis, Whitfield[6]; Caprinella quadrangularis[6]; Caprinella occidentalis, Whitfield[6]; *Caprinella gigantea, Whitfield.[6]

Fossils marked with an asterisk are also reported from Cambridge beds.

This fauna is peculiar in its generic association, the numerical preponderance of Rudistes and corals, the sparse representation of Pelecypoda, and the almost complete absence of Echini, Cephalopoda, and Brachiopoda, which so largely prevail in the Marine Cretaceous, and its general dissimilarity to Cretaceous faunas elsewhere than in the Great Antilles.

Foraminifera abound in the rocks of the Jamaican sequence from the limestone beds of the lower Blue Mountain Series[7] to the present, and living forms occur in great quantities in the surrounding waters. The fossil forms which will be frequently alluded to in this paper are of many species; some are of great diagnostic value, especially the species of Orbitoides and Nummulinæ, which, as will be shown, are only found doubtfully in the uppermost Cretaceous and Eocene (old usage) beds of the island. A correct appreciation of the stratigraphic occurrence of these and the other Foraminifera in the Jamaican sequence has been greatly confused in literature by the writings of W. J. L. Guppy, who published that they all came from beds of the Miocene age. Inasmuch as his deductions have seriously misled other authorities, like Jones,

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[1] Identified by T. W. Vaughan. Collected by Robert T. Hill, except the Cyathoseris haidingeri.

[2] Identified by Duncan. Collected by Jamaican Surveys.

[3] Identified by T. W. Stanton. Collected by Robert T. Hill.

[4] Identified by Woodward. Collected by Jamaican Surveys.

[5] Identified by Etheridge. Collected by Jamaican Surveys.

[6] Identified by Whitfield. Collected by Nichols.

[7] The conditions of formation of the lower part of the Blue Mcuntain Series were in general unfavorable for their occurrence.

Parker, and Dall, it is necessary to give a brief synopsis of them to straighten out the complications.

Soon after the discovery of Orbitoides and Nummulinæ in the Jamaican rocks by the official surveyors, and prior to Jones's studies, Guppy noted the discovery of similar forms in the asphalt rocks of the cliffs at San Fernando, Trinidad.[1] In these papers he also stated that "the same species of Foraminifera had been detected in the Miocene rocks of Jamaica.[2] He said,[3] "I have not detected any other organisms in the same bed as the Orbitoides and Nummulites; but both above and below it are found Tertiary fossils, probably not of more recent date than the Miocene age." Sufficient "to state that the evidence derived from them is not inconsistent with the presumption of the Miocene origin of the deposits in question. We know too little as yet of the Tertiaries of this part of the world to be able to pronounce a more decided opinion; but should the supposition of the Middle Tertiary age of the San Fernando Tertiaries be ultimately established, *we should have here the remarkable phenomena of the association of an Old World with a New World form of Lower Tertiary rhizopod in a deposit of Middle Tertiary age.*" Furthermore he says:[4] "Upon a close examination of the vertical mass [of asphaltum rock[5]] is found to consist chiefly of the remains of Nummulites and Orbitoides, two genera of Foraminifera whose shells, as is well known to geologists and paleontologists, form in various parts of the world thick masses of rock; the Orbitoides being generally characteristic of the Eocene period in the Western Hemisphere, while the Nummulites is regarded as indicative of the Middle Eocene in Europe and Asia. Here, however, we find the remains of both these genera in strata of supposed Miocene age."[6] Thus, with probable correctness, he correlated the Jamaican Orbitoidal beds with those of Trinidad, but erroneously referred both to the Miocene age (old classifications).

In 1863 Jones and Parker described a group of Foraminifera collected by Barrett from the Pteropod marls of Eastern Jamaica of supposed Pliocene and Pleistocene age, and differing entirely both in stratigraphic

[1] See Proceedings of the Scientific Association of Trinidad, December, 1872, Port of Spain, 1873. In this paper Mr. Guppy notes that he announced the discovery of these forms in Trinidad at a previous meeting of the society in July, 1863.

[2] See also Proc. Sci. Association of Trinidad, 1867, p. 15.

[3] The Geologist, London, 1864, Vol. I. p. 160.

[4] *Loc. cit.*, p. 159.

[5] Figured on page 38 of Trinidad Reports, 1860.

[6] A Report on the Geology of Trinidad, pp. 33 and 102.

position and in species from the Orbitoidal horizons previously mentioned by Barrett, Woodward, Duncan, and Wall, and Jones himself.[1] In the same Report[2] Jones and Parker described a large foraminiferal fauna dredged from the ocean off Jamaica by Barrett, which consisted of recent species almost identical with those of the Pteropod marls. Neither of these collections contained Orbitoides, Nummulites, or any of the more ancient forms of Foraminifera mentioned in the previous literature. In 1867 Guppy tabulated a few species of Foraminifera from the Pteropod marls above referred to and the Orbitoides and Nummulinæ together, and cites them all as coming from "the Upper Miocene of Jamaica."[3] In 1874 he again tabulated all the Foraminifera from the Pteropod marls and recent dredgings in one group with those from the Orbitoidal and Nummulitic horizons, as coming from the Miocene of Jamaica.[4]

Finally, after successively placing the Orbitoidal and Nummulitic horizons in the Lower Tertiary, the Upper Miocene, and the Miocene respectively, besides mixing them with forms which are definitely known to come from entirely distinct horizons, Guppy in 1892 admitted[5] that the San Fernando (Naparima) Orbitoidal and Nummulitic beds of Trinidad which he originally considered Miocene were probably of Eocene age. Inasmuch as all his references of the Orbitoides beds of Jamaica to the Miocene were based upon their supposed resemblance to these Trinidad beds, this last conclusion clearly cancels his many previous references of the Orbitoidal limestones of the West Indies to the Miocene age.

Fossil Orbitoides were first reported by Barrett in 1860,[6] from the limestones included in our Blue Mountain Series, and these fossils were stated by him to be "of Cretaceous age in Jamaica."[7] Specimens from his collections were sent to England, where they were studied and commented upon by Woodward, T. Rupert Jones, Duncan and Wall, and others.[8]

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[1] Jones and Parker, British Association Report, 1863, p. 80.

[2] Ibid., p. 105.

[3] Proc. Sci. Association of Trinidad, December, 1867, p. 167.

[4] Geological Magazine, London, 1874, p. 21.

[5] Quart. Jour. Geol. Soc. London, Vol. XLVIII. p. 520.

[6] In a report referred to by the Governor of Jamaica, in the first message of February 7, 1860, printed in Jamaican Reports, 1869, p. 76, he says that Orbitoides are Cretaceous in Jamaica.

[7] Jamaican Reports, p. 76.

[8] See references following.

In 1863 the material collected by Barrett and mentioned by Woodward, was reported upon by T. Rupert Jones.[1] Orbitoides are included in the list of Cretaceous fossils given by Etheridge,[2] and alleged to occur with Nerinæa and Rudistes by Woodward,[3] and Duncan and Wall.[4]

Woodward[5] reported both Orbitoides and Nummulinæ from the "Hippurite limestone" of Jamaica, which "is unlike that of any English stratum. It abounds in small oval bodies related to the Tertiary Nummulites, and also contained Radiolites, Inocerami, a large Nerinæa, and an Actæonella resembling *A. lævis* d'Orb." We have not personally observed Orbitoides in the Jamaican Cretaceous rocks, although they abound in the Eocene, as will be shown on a later page. Cretaceous limestones from Costa Rica, described in our Panama Report, show a mixture of remains very suggestive of the one described. The occurrence of Orbitoides and Nummulites, which abound in the Eocene formation, is more fully discussed on later pages.

Duncan asserted[6] that the corals were mostly European forms, "the majority have very decided facies, . . . suggestive of a close alliance of the great coral fauna of Gosau in the Eastern Alps," while others were alleged to be "common forms in the Kriedensmerle." He also stated[7] that "there is a community of species of corals between the Lower Chalk of Gosau and Piesting and the French Hippurite limestone at Martigues, the Corbières, and Uchaux. . . . It is clearly this assemblage of forms which is represented in Jamaica; and it is an interesting fact that the specimens from Gosau, Mount Hindmost, and Trout Hall present the same mineral aspect; in fact, the specimens are barely to be distinguished." Vaughan, who has recently re-examined Duncan's collections, does not agree with his conclusions, and states that they have no affinities with the Gosau forms. The Gosau (Cretaceous) forms are Senonian, and do not belong to the lower horizon to which Duncan referred them. Furthermore, two of the species mentioned by Duncan from Trout Hall and Upper Clarendon, *Diploria crassolamellosa*, Duncan (non Edwards and Haime) = *Diploria conferticostata*, Vaughan, and *Heliastræa exsculpta*, Duncan (non Reuss) = *Multicolum-*

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[1] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. p. 514.
[2] Jamaican Reports, p. 310.
[3] "The Geologist," Vol. V. p. 373.
[4] Quart. Jour. Geol. Soc. London, 1865, Vol. XXI. p. 2.
[5] S. P. Woodward, in the Geologist, London, 1862, Vol. V. p. 373.
[6] Quart. Jour. Geol. Soc. London, 1865, Vol. XXI. p. 11.
[7] Ibid., p. 12.

nastræa cyathiformis (Duncan), are also found in the Cambridge Eocene, and are Eocene species.

There are several species of corals in our collections from Jerusalem Mountain, including, according to Vaughan, a Cladocora, — a genus not hitherto found fossil in the West Indies. Vaughan remarks that there are other undetermined species from the Cretaceous of Jamaica different from those already reported by Duncan. Nowhere in the Continental American Cretaceous, except in Southern Mexico described by Felix and Lenk, is there a diversified coral fauna, and the latter belongs to lower beds. No comparison has been as yet instituted between the Mexican-Jamaican Cretaceous corals, however.

The Mollusca, with the exception of the Rudistes, are very poorly represented. The eight genera of Gastropoda found are all poorly preserved casts, mostly from the Jerusalem beds, with the exception of Actæonella, which also occurs in the Logie Green. The four pelecypods other than the Rudistes are mostly from the upper marls of the Jerusalem beds. This faint representation of Pelecypoda in the Cretaceous of Jamaica is a most remarkable feature. Numerically the fauna is predominantly Rudistean; these forms always occur in all the fossiliferous beds, even when others are unrepresented. They compose the mass of the Jerusalem limestones, and occur singly in the occasional clay beds of the Ballard and Catadupa beds.

Specimens of this Rudistean fauna collected by Nichols have recently been described by Whitfield.[1] It is unique in specific features, being entirely different from that of Europe and North America, especially that of Texas, where Rudistes are very numerous in the Edwards formation of the Lower Cretaceous (unless *R. nicholassi* is allied to a form of the Upper Cretaceous of Alabama and Texas). The absence of the genus Hippurites, so abundant in the Upper Cretaceous of Europe and Southern Mexico, is also noticeable, although this genus is missing from the Cretaceous of the United States. One genus, Barrettia — included in the Rudistes by Woodward,[2] and recently asserted by Whitfield[3] not to belong in this group at all — has no known representation elsewhere with the possible exception of Guatemala, where it has been questionably reported by Sapper.[4]

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[1] Bull. Am. Soc. Nat. Hist., New York, 1897, Vol. IX.

[2] The Geologist, London, 1862, Vol. V. pp. 372, 377.

[3] Bull. Am. Soc. Nat. Hist., New York, 1897, Vol. IX. pp. 233–246, Plates XXVII.–XXXVIII.

[4] Reported by Sapper from Guatemala. Physical Geography of Guatemala. Petermann's Mitteilungen, No. 113, Gotha, 1894, p. 9.

With this exception not a single species of the fauna has been reported from the North or South American Mainland. Probably the same fauna occurs in Cuba and Haiti, judging from papers by G. F. Matthew[1] and Tippenhauer.[2] It is also possible that it may occur in Guatemala and Costa Rica, or even Southern Mexico, where large unstudied Rudistean faunas abound. As will presently be noted several of these species of Rudistes also occur in the overlying Eocene (Cambridge) beds.

The most numerous and conspicuous forms of the Jamaican Cretaceous fauna are genera which proportionately have but slight representation in the North American Cretaceous, such as the corals, Rudistes, Nerinæa, and Actæonella, while on the contrary there seems to be an almost entire absence in the Jamaican fauna of such forms as Ammonites,[3] Trigonia, Gryphæa, Exogyra, Brachiopoda, and Echinodermata, which are so characteristic of the North and South American Cretaceous of Atlantic sedimentation. The Jamaican Cretaceous fauna, which is the oldest known life of the Great Antilles, is unique. Several Rudistes and two species of corals from these supposedly Cretaceous formations continue upward into the beds which are here placed in the Eocene, indicating a gradation of the faunas of these two epochs, as further discussed on a later page. It may possibly be explained upon the hypothesis that it lived adjacent to an insular land, separated from the continent by great depths of oceanic water which prevented migration to it of the main littoral fauna in its entirety. These beds represent the expiring days of the Cretaceous and can hardly antedate the Senonian in age.

THE EOCENE FAUNAS.

The existence of Eocene strata in Jamaica has hitherto been a question difficult to determine owing to the previous confusion of knowledge of the stratigraphy and paleontology. It is our opinion that the Eocene is well represented by at least two distinct formations, the Richmond and Cambridge, and by three, if the Montpelier formation, which is the equivalent of the Vicksburg stage, is included in the Eocene, as has been customarily done by all American writers until recently, when Heilprin and Dall, following Conrad, have again placed the Vicksburg in the base of the Oligocene.

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[1] Canadian Naturalist, 1872, Vol. VII. p. 19.

[2] Die Insel Haiti, Leipzig, 1893. See Plate preceding page 381.

[3] Ammonites have been reported in one locality only in Jamaica (page 78), but their occurrence there has not been verified or accepted by the paleontologists of the Survey.

These three formations, although distinct in lithologic characters, grade into one another, the Richmond being a littoral, non-calcareous clastic formation, the Cambridge a mixed calcareous and argillaceous littoral, and the Montpelier a truly deep sea foraminiferal chalk deposit.

De la Beche, the earliest writer on the geology of Jamaica, placed the beds included in our Richmond beds, in his medial, or Carboniferous Series,[1] and included the Cambridge in the base of his "White Limestone," now known to embrace formations from Eocene to recent inclusive, the Miocene excepted. He referred the fossils from the base of this series (our Cambridge beds) to the Eocene, and considered them to "belong to the same age as the London Clay, *Calcaire grossier* of the Paris Basin," and published a figure of one of the large Cerithiums[2] peculiar to it.

Duncan and Wall, and others connected with writing up the Jamaican Reports, referred the beds of our Richmond formation to the Eocene, but expressed many confusing opinions concerning the age of the beds we have placed in the Cambridge and Montpelier, some of the writers having referred them at first to the Eocene, — which conclusion was finally abandoned by Etheridge and others, who confused them with the Miocene strata. These beds, which underlie the white limestones, were at first considered Eocene by C. B. Brown and other field workers in the western parishes, but through the unfortunate miscorrelation on the part of the workers in the eastern parishes, as explained in the Introduction of this Report, they were confused with the Bowden beds, which overlie the white limestones, and all conception of their true position was completely obliterated.

C. B. Brown[3] described the Yellow Limestones (Cambridge beds) with Orbitoides in St. James, "which agrees with descriptions of Claiborne, Jackson, and Suggsville beds." He noted that no provision had been made by the government for a critical examination by a paleontologist; "therefore until such has been made, the subject must remain unsettled." He also referred to a list of fossils from this formation in the Appendix of the Report, but does not give it. It is a singular fact that the species of this fauna were apparently never seen nor studied by the English paleontologists, into whose hands fell the official collections of the Jamaican Surveys.

Sawkins's published views are conflicting. At one time in discussing the "Yellow Limestone of Trelawney" (our Cambridge beds), he describes them as "Orbitoidal limestones, which agree with the descriptions of the Claiborne beds by Sir Charles Lyell and Mr. Dana."[1] In two other places he referred them to the Mid-Tertiary period, on stratigraphic grounds, because they occurred between the Eocene (our Richmond beds) and the White Limestone, the latter of which he (Sawkins) erroneously considered Pliocene.[2] These original opinions on the part of the field workers to the effect that the beds were Eocene were abandoned by the authors of the Summaries of the Jamaican Reports, who, writing in England, confused the identity of the (Cambridge) Yellow Limestone underlying the great White Limestone Series (Montpelier and Moneague formations) with the Bowden Oligocene beds overlying it, and erroneously supposed the latter to be the base instead of the top of the White Limestones. In this manner the identity of the Cambridge Eocene faunas was confused with that of the Oligocene, and the age of the whole Jamaican sequence above the Richmond so jumbled that it has become impossible to obtain a correct knowledge of it from the literature concerning the island, even that of the most recent writers, like Jukes-Browne and Harrison, who have said that the upper division of the Miocene "is doubtless the true place of the Jamaican Yellow Limestone."[3]

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[1] Trans. Geol. Soc. London, 1826, No. 36, pp. 157–163.

[2] Ibid., p. 171.

[3] Jamaican Reports, p. 244.

So confusing has the literature become that of late years there has been a tendency to deny that the rocks of the Eocene were present in the West Indies. The most recent summary of these formations[4] omits it in this region with the doubtful exception of the Manzanilla beds of Trinidad. One gratifying result of our researches is the presentation of additional proof that the Eocene period is represented in Jamaica, not alone by the doubtful Richmond beds, but also by the Cambridge formation, and that these collectively constitute one of the most distinctive and important formations, not only of this island, but of all the great Antilles, Barbados, Trinidad, and perhaps the Windward Islands, as will be shown in later pages.

The Richmond Beds.

In the Richmond beds animal remains are exceedingly rare. A Natica, a Turritella, and what is probably a large Scalaria associated with two doubtful species of supposedly Eocene corals described by Duncan, have been found in the conglomerate of Point Haldane, at

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[1] Jamaican Reports, p. 224.

[2] Ibid., pp. 130, 138.

[3] Quart. Jour. Geol. Soc. London, Vol. XLVII. pp. 197, 242.

[4] Dall, "Descriptions of Tertiary Fossils from the Antillean Region." Proc. U. S. National Museum, Vol. XIX. pp. 303, 305. Washington, 1896.

Port Maria. Duncan and Wall have also reported one species of Eocene coral from the black shale of the Blue Mountain Series from the valley of the Yallahs River on the south side of the island, east of Kingston.[1] Etheridge[2] also mentions a Melania and a Turritella from these beds. A small Modiola has also been found in the formation at Arthur's Seat. When the impure turbulent conditions of the sediments are considered, which are very similar to those of the Lignitic group of our Southern States Eocene, this scarcity of fossil remains is not surprising. Plant remains occur nearly everywhere in the laminæ of the clays.

In all, the following species have been reported from the Richmond beds: —

Paracyathus crassus, Ed. & H.;[3] Stylophora contorta, Leym.;[4] Stylocœnia emarciata, Lam. (Duncan),[4] = St. duerdeni, Vaughan; Columnastræa eyeri, Dunc.;[4] Modiola, sp.;[5] Melania;[4] Turritella;[4] Scalaria;[4] Rudistes;[4] [6] Caprinella;[4] [6] Actæonella;[4] [6] Natica phasianelloides.

The supposedly Eocene corals of Duncan, with one exception, were found in the gravel and shale beds of the Richmond formation at Port Maria. They are depauperate forms, which apparently gained foothold with difficulty in the disturbed and muddy waters of the Richmond epoch. Concerning these Duncan and Wall[7] wrote as follows: —

"The specimens from Port Maria are either dark and carbonaceous-looking, or are encrusted on a fine dark purple conglomerate; all are very significant of the horizon, and recall the puny development of the species of the London Clay. The Paracyathus from Yallahs Valley resembles that of the London Clay, being even stained black, like the Sheppy specimens; the *Stylocœnia emarciata* is a well known form in British, French, Italian, and Sindian early Tertiary collections, and the *Stylophora contorta* also. The Stylocœnia and Stylophora are characteristic corals, and denote an Eocene horizon; and they indicate, when unaccompanied by other species, the existence of physical conditions not favorable for coral growth."

Vaughan has described Duncan's *Stylocœnia emarciata* as *Stylocœnia*

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[1] Paracyathus, sp. Quart. Jour. Geol. Soc., Vol. XXII. p. 8.

[2] Jamaican Reports, p. 311.

[3] Upper Valley of Yallahs River.

[4] Point Haldane, Port Maria.

[5] Arthur's Seat, Clarendon.

[6] Reported by Etheridge (Jamaican Reports, p. 311), who surmised that they were derived from "Hippurite limestone below." No "Hippurite" limestone is known to occur below the beds at Port Maria, or within any reasonable distance.

[7] Quart. Jour. Geol. Soc. London, 1864, Vol. XXI. p. 13.

duerdeni. The association together of species of *Stylocœnia* and *Stylophora*, both being close to Eocene species of Europe, would make the probability in favor of the Eocene age of the beds. Therefore the paleontologic evidence, though not conclusive, supports the opinion of Duncan regarding the age of the beds. Fortunately the stratigraphic position of the Richmond beds is clearly made out, independent of the fossils, so in this case positive paleontologic proof is not essential for determining their position. We studied the locality of Port Maria from which these corals came in order to ascertain their stratigraphic position, which beyond doubt is that of the typical Richmond beds.

Etheridge[1] mentions the occurrence of fossil Rudistes in these beds, but suggests in explanation that their presence might be accounted for upon the hypothesis that they could be water-rolled survivals of the denudation of the lower lying Cretaceous beds. Whether the specimens of "Hippurites," Radiolites, and Actæonellas noted are indigenous to these particular beds or not, we cannot state, not having been so fortunate as to find any of the fauna *in situ.* We question the conclusion, however, that they are derived specimens, because similar forms of Rudistes at least were found by us *in situ* in the overlying Cambridge beds, as will be shown presently. It is probable, as shown in the Ballard bed of the Minho section, that these Rudistean forms appeared in sporadic colonies throughout the thickness of the black shales of the Minho and Richmond beds, and continued into the Cambridge formation. Whoever undertakes the further study of these beds must remember that specimens of free and well preserved Rudistes should not be confused with the rolled pebble of hard crystalline limestone of the Jerusalem type which should also occur.

The presence of the supposedly Cretaceous Rudistean genera would ordinarily invalidate the data upon which the Eocene age of the Richmond beds hitherto depended for establishment, were it not for our positive evidence to be presented that these forms are found *in situ* in overlying beds, associated with undoubted Eocene fossils. The other species are all of Eocene facies and point to their Eocene age, which conclusion we are able to fix with positiveness by the evidence of the overlying Cambridge beds, where a similar mixture is found, whose true nature has hitherto escaped observation.

The Cambridge Formation.

From a paleontologic standpoint these beds mark one of the most interesting and valuable horizons in the whole Jamaican sequence, inasmuch as it contains a distinctive fauna abundant in specimens if not in species, including several species of Cretaceous fossils which have transgressed into the Eocene. The three members of the formation, the Catadupa, Chapelton, and Port Antonio respectively, are paleontologically allied, the only difference being that some of the characteristic corals, Rudistes, and some mollusks of the former, do not range up into the latter.

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[1] Jamaican Reports, p. 311.

The Catadupa Beds. — The outcrops along the Montego Bay Railway on the east slope of Great River Valley, on the borders of St. James and Hanover at Cambridge and Catadupa, are by far the best localities we have seen for collecting. We have twice visited these localities for that purpose. The material is very abundant, but most of the Mollusca are poorly preserved. It contains many determinable species of Foraminifera, Echini, and Mollusca, which have been submitted to various specialists. The fauna so far as studied is as follows: —

(1) From railway cuttings near Catadupa and Cambridge. Foraminifera. — Many small granular Foraminifera, occurring in vast numbers in the shale beds, giving it an oölitic texture on indurating. The following species were determined by Bagg: —

Miliolina subrotunda, Montague, Catadupa; M. cicularis, Borneman, Catadupa; M. seminulum, Linné, Catadupa and Cambridge; M. sp., Catadupa; Textularia trochus, d'Orb., Catadupa; T. barretti, P. and J., Catadupa; T. seminulum, P. and J., Catadupa; Haplostiche soldani, P. and J., Catadupa; Pullenia sphæroides, Cambridge; Miliolina seminulum, var. triangularis.

Corals. — The following corals were determined by T. W. Vaughan: —

From near Cambridge Station, St. James Parish: Turbinoseris jamaicaensis, Vaughan; Turbinoseris cantabrigiensis, Vaughan; Dendracis cantabrigiensis, Vaughan.

From Catadupa: Trochosmilia hilli, Vaughan; Multicolumnastræa cyathiformis, (Duncan); Diploria conferticostata, Vaughan (= D. crassolamellosa, Duncan, non Edwards and Haime); Diploria conferticostata, var. columnaris, Vaughan; Trochoseris catadupensis, Vaughan; Mesomorpha catadupensis, Vaughan.

Echinoderms. — Scutellina,[1] Cambridge and Catadupa; Acrocidaris,[1] Catadupa; Rapinot pneustio,[2] Great River; Diplopodia,[2] Great River; Echinolampus,[2] Great River; Echinanthus,[2] Retrieve.

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[1] From my collections.

[2] From the collections of the Institute of Jamaica. Macropneustes and Pygorhynchus have also been collected from this formation at Mountain Spring, St. Elizabeth, and Maroontown.

T. W. Stanton of the United States Geological Survey has kindly furnished the following determinations of the Mollusca collected by me: —

(*a*) From near Catadupa: — Ostrea, sp.; resembles young of O. compressirostra. Carolia jamaicensis, Dall; this is an Eocene genus. Caprinula gigantea, Whitf.[1]?; a fragment. Caprinella occidentalis, Whitf.[1]; a small specimen. Caprina jamaicensis, Whitf.[1]; several small specimens. Radiolites rudis, Whitf.[1]; four specimens (lower valves) that seem to belong to this species. Radiolites adherens, Whitf.[1]?; one specimen doubtfully referred here. Radiolites, sp.; several fragments of a small strongly plicate species that cannot be satisfactorily identified with any of those described by Whitfield. Caridum, sp.; rather large form. Natica, sp.; casts. Nerita, sp.; a medium sized smooth form. Cerithium, sp.; 1, Cerithium, sp.; 2, fragmentary cast of very large species. Thalassa? sp.; a Purpuroid shell resembling this genus, represented by a fragment. Cypræa, sp.

(2) From the Railway Cuttings at Cambridge.

The collection from Cambridge is not so large, but it contains enough identical species (marked *) to show that the same horizons are represented as at Catadupa.

(*b*) From near Cambridge: — *Ostrea, sp. Anomia, sp. *Carolia jamaicensis, Dall. Spondylidæ (?) genus undetermined; a peculiar shell having the form of an Ostrea and resembling a Chama in sculpture and shell structure. *Radiolites rudis, Whitf.? a single small specimen. Protocardia, sp. Cardium, sp. Lucina, sp.; large casts. Nerita, sp. Cerithium, sp.; a very large form resembling one of the huge species from the Paris Basin Eocene.

Several other indeterminate casts of bivalves and gastropods. The genus Cassis was also identfied from the Cambridge collection by Dall. A fragment of a Nerinæa also occurs.

Chapelton Beds. — The upper beds at Chapelton are of later and slightly deeper water origin than the Catadupa, and mark a stage in the great Eo-Oligocene subsidence and a transition between the Cambridge and Montpelier. They are characterized by the same little Alectryonate oyster, large Cerithium and Lucina, which are found at Cambridge. Several large Echinoderms occur in this horizon. None of the other fossils of the Catadupa beds were noticed by us, while a species of Orbitoides (the species referred to *O. mantelli* throughout the Jamaican Reports[1]) becomes exceedingly abundant, constituting the larger part of both the marls and limestones.

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[1] Forms hitherto supposed to have been peculiar to the Cretaceous beds of Jamaica.

In all, this fauna has three species of mollusks connecting it with that of Catadupa, but a large number of peculiar fossils characterizing the latter are absent. The molluscan forms occurring in the Chapelton beds are those which have survived from the Catadupa beds, just as the Rudistes of the latter have survived from the lower beds. The difference in the prevalent Foraminifera is one distinction between the beds, Orbitoides, which have not been found at Catadupa, characterizing the Chapelton beds, while the former contains immense quantities of other species as enumerated. At Lower Chapelton the following fossils were collected by me: Orbitoides,[2] Anomia,[2] Lucina,[3] oyster,[3] gastropod.[2]

The same "Yellow Limestone" at Mile Post 17½, Lucea, and Savanna-la-Mar road contains Crustacea,[2] Lucina,[2] Cardium,[2] gastropod,[2] simple Coral,[3] Corbis.

The Port Antonio Beds. — At a locality west of Port Antonio we collected casts of the large Cerithium and Lucina previously mentioned, and a Vulsella, which characterize the Cambridge beds, and also several casts of smaller mollusks, alternating with granular chalks made up of Foraminifera, including some similar to those found at Catadupa. Bagg reports the following species of Foraminifera from this locality: Globigerina dutertrei, d'Orb.; Globigerina bulloides, d'Orb.; Milolina reminulum, Linné; Amphistegina lessonii, d'Orb. (A. hauerii, d'Orb.); Orbitoides fortissii, d'Arch.; O. papyracea; O. complanata; Orbulina universa; Nodosaria; Vaginulina; Nummulites, sp.; Heterostegina; Discorbina.

The material in which these fossils occur at this locality from its lack of color would ordinarily be classed as a white limestone; the beds represent a gradation of one of the formations into the other. The fauna is that of the Cambridge beds (Chapelton and Catadupa), and indicates that either the lithologic nature of the latter has changed from a mixed to a pure oceanic character in this portion of the island, or there is a faunal continuity between it and the base of the Montpelier.

In addition to the forms of the Cambridge beds above mentioned, Etheridge[4] has noted that "A portion only of a Nautilus has been found in the Yellow Limestone of Spring Mount, St. James" Parish in the same valley as Catadupa and Cambridge. This is the only Cephalopod as yet found in Jamaica, and is probably the same form which has been referred to as *Aturia zigzag*. If its position and determination could be verified, it would prove another valuable testimonial to the Eocene age of the beds, as this form is characteristic of the late Eocene of the United States. De la Beche[1] has noted the occurrence of a Nautilus, probably the same as that previously mentioned from Cuba, a Terrebratula, and Nummulinæ in association with other species near Halse Hall House, Clarendon. No other specimens of fossil Cephalopoda have been found in Jamaica.

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[1] As determined by T. Rupert Jones. See Jamaican Reports, p. 313, and Geol. Magazine, London, 1800, pp. 102, 103.

[2] Found at Catadupa and Cambridge.

[3] No. 81 of Institute collection.

[4] Jamaican Reports, p. 328.

Of the fossil Mammalia, only a single fossil trace has been discovered in Jamaica, *Prorastomus sirenoides* Owen,[2] a species of Sirenia related to the Manatees of to-day. This specimen was reported from Freeman's Hall Estate in the southeastern corner of Trelawney near the centre of the island. The locality from which this specimen came is a typical outcrop of the Cambridge beds as described by Brown,[3] and Owen's description of the material in which the specimen was embedded conforms also to the lithologic character of that formation. While no final opinion can be expressed without seeing the specimen and locality, the evidence certainly points to the early Eocene age of this animal.[4] Being a marine animal, its occurrence in the rocks of Jamaica is of no significance in tracing previous relationships of Jamaica to other islands.

This fauna of the Cambridge formation is remarkable in several ways. First, for the peculiar mixture it affords at Catadupa of Eocene and Cretaceous genera; and secondly, from its collective dissimilarity to any other known fauna, especially to those of the American continental littoral formations. When a small collection from Cambridge was collected by us in 1896 and submitted to a Tertiary paleontologist of note, it was rejected by him on the ground that it was not of Tertiary age, but Cretaceous, and this too before true Rudistes had been recognized in it. Recognizing its absolute dissimilarity to any known American Cretaceous fauna, we revisited the region in 1897, and discovered the more extensive exposure at Catadupa where the Rudistes occurred in great abundance. From this last collection Dall identified the Carolia, hitherto known only in the lowest Eocene of Egypt.

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[1] Nautilus Cubensis, Lea. Trans. Am. Phil. Soc., 1841, Vol. VII. p. 259.

[2] Quart. Jour. Geol. Soc., 1855, Vol. XI. pp. 541, 543.

[3] Jamaican Reports, p. 224.

[4] Marine deposits of the Cretaceous and early Eocene periods are recognized all over the world, but not a trace of the Cetacea and Sirenia have been found in them. So far as known, these types appear fully evolved at the top of the Eocene. —Nat. Science, October, 1897, page 223.

None of the species of the Cambridge beds excepting the Rudistes, the gigantic Cerithium (?), an oyster, and a Lucina, have been reported before from Jamaica. The eight species of corals identified by Vaughan are entirely distinct from the species hitherto reported from the Richmond beds at Port Maria by Duncan; the Spondylidæ (?), Nerita, Carolia, and Cypræa are forms which apparently were nôt found by the geologists of the British Survey. Not a single one of the species (described or undescribed), is like any of the North or Central American forms, unless it is the small Alectryonate oyster and the Cardita. Some of the corals have European analogues if not specific identity; the gigantic Cerithium-like casts are somewhat similar to forms in the Paris Basin, while the Carolia, as before stated, is a genus hitherto reported from Egypt.

The Orbitoides of the Chapelton beds, which is a comparatively large species from five millimeters to a centimeter in diameter, occurs in vast numbers in the impure littoral sediments. So abundant are these forms in the parishes of St. Mary, Clarendon, and elsewhere, that the formation could well be termed the "Nodular Orbitoidal Limestone," as it was originally designated by Barrett,[1] were paleontologic names still in vogue. Jones was the first to note the occurrence of Orbitoides in the nodular limestone[2] (our Cambridge beds), No. 4 of Barrett's (Woodward's) section,[3] previously specifically reported only in the Hippurites limestone by Woodward and Barrett. He remarked that "In the Western Hemisphere Orbitoides and Nummulinæ are very rare above the Eocene group," and that it may be remarked as a point of interest that the Nummulites and Orbitoides of Jamaica are such as are found in South Europe and India. From these nodular Orbitoidal limestones Jones reported Orbitoides and three or four Nummulinæ. Concerning these he said:[4] "In the Nodular Orbitoidal Limestone of Jamaica [Cambridge beds, R. T. H.] at the base of the White Limestone, . . . I find a few rather small specimens of the same variety of

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[1] As published by T. Rupert Jones. In the text Jones states that he "understood Mr. Barrett to have informed him that the Orbitoides occurred in nodules in clay just underneath the great White Limestones." Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. pp. 514, 515.

[2] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. p. 515.

Geologist, London, 1862, Vol. V. p. 373.

Geological Magazine, London, 1864, Vol. I. p. 104.

O. mantelli as that so abundant in the Antiguan flint." He also states[1] that "the Orbitoides are similar to those found fossil in the Upper Chalk of Southern France and the Pyrenees, and in the Nummulites beds of Scinde."

The corals identified by Vaughan are species not hitherto found in Jamaica, and constitute a valuable addition to its fauna, inasmuch as they fix the Eocene position of these beds beyond doubt. He submits the following notes.

"The Cambridge beds can be referred to the Eocene (or possibly Oligocene) on the strength of their containing abundant specimens of *Dendracis*. This genus is not known from rocks older than Eocene or younger than Oligocene. Both specimens and species are abundant in Southern Europe and Northern Africa in strata of these ages.

"The Catadupa beds also appear to be Eocene on the evidence of the *Trochosmilia*, which has a near European relative in *T. acutimargo*, Reuss. The *Diploria* also has a European analogue. *Trochoseris* is a doubtfully Cretaceous genus; it occurs in the Eocene, and there is a recent species.

"The faunas from the Richmond, Cambridge, and Catadupa beds seem quite different from the St. Bartholomew fauna, described by Duncan. Apparently they possess only one species in common, viz. the *Stylocœnia*, identified by Duncan as *emarciata*. The stratigraphic affinities of the Jamaican species for European species are the same as those of the St. Bartholomew corals, and I believe more extensive study and collecting will show considerable resemblance, — especially after a revision of Duncan's types from St. Bartholomew."

Concerning the eight species found by Vaughan, he says that "there is not a strictly Cretaceous form in the collection from Catadupa and Cambridge, . . . so the corals have afforded no evidence tending to prove the Cretaceous age of these beds, but it all, so far as it is definite, points to an Eocene age." They too occurred in muddy waters, but more calcareous than those of the Richmond epoch, and are accompanied by a large molluscan fauna.

The two or three genera and species of Echinodermata submitted to Agassiz were reported by him to be Tertiary forms.

The mollusca of the Cambridge beds, while few in species, as a rule are sufficiently abundant and well preserved to present a distinct faunal aspect. Fortunately these have escaped the non-resident species makers, who have thrown all other Post-Cretaceous Jamaican fossils into the

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[1] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. p. 514.

Miocene, and we are enabled to present it for the first time with appropriate stratigraphic data.

In addition to the Rudistes of Catadupa already described, this fauna furnishes many new species of Mollusca, all of which are apparently quite distinct from those of the Eocene beds of the North American Coastal Plain. More of the forms, as Cerithium and Lucina and Cardium, are very large and robust. Of the genera, one at least is new, and still unnamed; another, Carolia, has not hitherto been found in America. The Catadupa beds also afford specimens of the gastropod genera Conus, Cypræa, and Thalassa, which have not been found below the Tertiary. There are many indeterminate casts of gasteropods in the Catadupa beds which have a striking resemblance to those of the Cretaceous beds of Jerusalem Mountain.

De la Beche has frequently noted the occurrence at many localities of the fossils which we now know to belong to the Cambridge beds in the base of his "White Limestone Series," such as the association of Ostrea, Echini, and two large species of Cerithium. In fact, the entire list of species given by him on page 170 of his work most probably came from the Cambridge beds. He figures one of the large species of Cerithium,[1] and states that at one time he "considered that it might have been a cast of a shell analogous to *C. giganteum*; the latter is, however, a much taller shell than the one under consideration, which in general outline resembles more the *C. cornucopiæ* of Sowerby."[2] It is an interesting fact that this fossil also occurs in the Virgin Islands and St. Bartholomew as noted by Cleve.

According to notes kindly furnished us by Stanton, "the evidence as to the age of the molluscan fossils from these two localities is conflicting The forms described by Whitfield under the names Caprinula, Caprinella, Caprina, and Radiolites, are all Cretaceous types, and the genera to which they belong are not known to occur elsewhere in more recent formations. On the other hand, all the other fossils that are well enough preserved to be recognizable, have a more modern aspect, none of them being characteristic of the Cretaceous. The genus Carolia occurs elsewhere only in the lowest Eocene of Egypt. The large species of Cerithium are of Eocene types, and the same may be said of the Cypræa and several other forms. At any rate, similar species are not known from beds as early as the Cretaceous. If the Rudistes and Chamidæ were absent, there would be nothing to suggest a Pre-Tertiary age for the beds.

The presence of Rudistes, supposedly Cretaceous genera, in this otherwise Eocene fauna, is a perplexing feature difficult of explanation. The occurrence of Rudistes and Actæonella in the supposedly Richmond Eocene beds of Jamaica, as recorded by the writers of the Jamaican Reports, has already been noted. Their unsubstantiated hypothesis that these might be rolled survivals of the lower beds naturally originates the inquiry if the Rudistes of the Catadupa beds may not be of similar occurrence. The writer can find no foundation for such an hypothesis in case of the Rudistes in the Catadupa beds. Many of the specimens collected were independent or unattached, resembling in appearance the free forms found in the higher occasional horizons of the Minho beds. The single specimens show no signs of having undergone attrition by rolling. The delicate lamellæ and corrugations, such as would be broken by the least possible attrition, are all preserved, as well as the soft chitinous structure of some of the species like *Caprina jamaicensis*, Whitfield. In fact, these forms show no evidence whatever of having undergone such treatment, and are much better preserved than any found in the Jerusalem beds of undoubted Cretaceous origin. In addition to the loose or free specimens, there was a solid stratum two feet in thickness made up of an agglomerate of these shells as thick as coral heads in reef rock, and absolutely *in situ*. Furthermore, it is difficult to see how such forms, if rolled, could have been sorted out and thus segregated without being accompanied by some of the hard enduring igneous pebble of the conglomerate beds of the Minho and Richmond formations, with and below which the lower Rudistes horizons are interbedded.

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[1] *Op. cit.*, Plate 21.

[2] *Op. cit.*, pp. 170, 171.

Elsewhere the lithologic resemblance of the supposedly undoubted Cretaceous beds to the Yellow Limestone has been noted by the Jamaican geologists,[1] and other fossils collected by us from the Minho River section are lithologically and specifically identical in every appearance with those of the Cambridge beds, including two of the typical Cambridge corals, also occur in the Rudistean Cretaceous beds of Logie Green and Trout Hall.

Another fact which reinforces the supposition that the mixture of these Cretaceous and Tertiary forms is natural is that the Jamaican geologists originally described the rocks of the typical Cambridge beds as "the Cretaceous or Hippurite limestone."[2] In fact, we discovered the Catadupa beds while making a vigorous search for the alleged Cretaceous beds which had been described as occurring between Chesterfield and Retreat, and the Catadupa and Cambridge outcrops were the only fossiliferous beds found.

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[1] Jamaican Reports, p. 233.

[2] Ibid., pp. 245, 246.

The statement of Barrett,[1] that Orbitoides "are Cretaceous fossils in Jamaica," may possibly have been based upon a knowledge of the association of these forms with the Cretaceous Rudistes.

In view of the facts presented, the writer finds it utterly impossible to accept the "rolled" hypothesis, and he can see no way of avoiding the positive conclusion that the Rudistean forms in the Cambridge beds represent a survival of Cretaceous types into the Lower Eocene. Such an occurrence would in no manner be more anomalous than many other facts connected with the peculiar insular faunas of late Cretaceous and early Tertiary time in Jamaica, mentioned in this Report. Even though the Rudistes should prove to be survivals, this Eocene fauna of Catadupa as a whole shows anomalies comparable to those exhibited by the Jerusalem beds, which mark it as peculiar. As a fauna, nothing exactly analogous to it is known elsewhere.

In view of the apparent mixture of Cretaceous and Eocene forms, question might arise concerning the position of these beds in the geological column. Inasmuch as all the other genera are Eocene, it is our opinion that it will be best to consider the beds of that age and to assume that the Rudistean genera have transgressed into the Eocene.

The fact that these beds are stratigraphically above the Richmond beds is another consideration which leads us to the Eocene conclusion. Inasmuch as the two species of coral from the latter (mentioned on page 126) attest the Eocene affinities of the latter beds, the discovery of the Cambridge formation gives a certainty to the existence of an Eocene system in Jamaica, aggregating at least 1,500 feet in thickness, which, in connection with the Montpelier beds to be described farther on, of supposed Vicksburgian facies, shows the Eo-Tertiary beds of the island to be far more extensive than hitherto supposed. The paleontologic peculiarities of the Richmond and Cambridge formations, analogous to those of the preceding Cretaceous beds, are such as can only be accounted for by geographic environment, and point to the early insularity of the island through Eocene time.

The relations of this fauna to other regions of the world is anomalous. Its affinities in some respects seem more analogous to those of the southern portions of Europe than to those of the United States, but we do not dare at present to make positive conclusions except to agree with Moore that "the fauna of the West Indian seas in those remote times appears to have been as remote from that of the shores of the United States as it has lately been shown by Mr. Bland to be at the present day."[1]

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[1] Jamaican Reports, p. 76.

Fossils of the Montpelier White Limestone.

As a rule, the Tertiary White Limestones which succeed the Cambridge beds, although almost entirely of organic origin, are singularly free from macroscopic fossils, especially the lower half of the Series. There is a current impression that the white limestones, as a whole, are richly fossiliferous, owing to the fact that many shells from the Bowden horizon have been described as coming from the "White Limestones of Jamaica," but, as we have shown, the Bowden beds are not White Limestones, but gravels and argillaceous marls. De la Beche notes many shells from the White Limestones, but all came either from the underlying Cambridge beds or the overlying Post-Tertiary White Limestones of the Coastal Series which we have separated from the true Tertiary White Limestones.

Minute search for such fossils in hundreds of exposures has generally been without success. Except the beds at Port Antonio, which are of Cambridge affinities, the Moneague beds and a few places in the Bog Walk section, the great mass of the White Limestones are barren of such emains so far as we have observed them. This noteworthy absence may in some instances be due to secondary alteration of the rocks, but, n general, it is owing to the fact that the material originated at depths beyond that in which the abundant littoral molluscan life occurred. Notwithstanding the absence of macroscopic remains, the Montpelier eds, which compose the lower 500 feet of the White Limestones, are lmost entirely made up of foraminiferal remains, — Orbitoides, Nummulinæ, and Miliolidæ at the base, grading up into Globigerinal deposits. These beds are very free from remains of shallow water corals, — a fact which further supports the theory that they were deposited at great epths beyond that at which these organisms could flourish. The great ubsidence of this epoch undoubtedly must have extinguished most of he dense molluscan life, which does not appear again until the Bowden poch.

Radiolaria are rare in the Jamaican rocks, our specimens from the Montpelier beds usually showing only a few traces of them, — certainly no well defined forms, — although a minute fragment or two in some of the collections are very much like Radiolarian tests. Nowhere on the island have rocks been found made up nearly entirely of these forms such as occur in Barbados, Haiti, and near Baracoa, Eastern Cuba. W. B. Hill has stated[1] that "one or two Radiolarians can be seen in outline in a rock in which Globigerinæ are conspicuously abundant," from Hanover Parish, — where the Montpelier beds occur.

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[1] T. C. Moore, Quart. Jour. Geol. Soc. London, Vol. IX. p. 131.

The lower White Limestones of the Oceanic Series are composed of chalk making Foraminifera, deposited in deeper waters than the preceding beds, and of these there are several distinct horizons each composed of a different character or association of Foraminifera.

Globigerinæ appear in great number, composing the chalky strata of the Montpelier beds on the north coast near St. Margaret's, the hill at Montpelier hotel, and the rocks underlying the northern side of the plain back of Savanna-la-Mar, Westmoreland.

W. B. Hill[2] has also described a specimen of white limestone from Hanover County, which he asserts is an "oceanic deposit," in which "thick-shelled Globigerinæ similar to those of the Barbadian rocks" are very abundant. Jukes-Browne and Harrison[3] have said that Colonel Fielden, who sent this specimen from Hanover, reported that flints were abundant in the formation. I do not hesitate from our acquaintance with this region to state that this specimen is from the Montpelier formation.

Orbitoides and Nummulinæ, which have already been noted as occurring in the Cambridge beds, continue into the Montpelier, as Bagg's studies of our specimens show, and from the specimens described by T. Rupert Jones the stratigraphic position of which we have been able to identify, thanks to his having given localities of material studied by him from Jamaica.

Bagg reports the following Foraminifera in our collection, from the Montpelier Formation.

Flints from Montpelier Hill (No. 75): — Orbitoides dispansus, Sowerby; abundant, Eocene. Orbitoides mantelli, Morton, rare; uppermost Eocene and lowest Oligocene. Orbitoides papyracea, Boubée, Eocene. Nummulites, probably.

These flints are Eocene.

Bluff at Dover: — Orbitoides mantelli, Morton. Orbiculina adunca, Fichtel and Moll. Amphistegina sp.

[1] Quart. Jour. Geol. Soc. London, 1892, Vol. XLVIII. p. 180.

[2] Ibid., p. 280.

[3] Ibid., p. 219.

Mile Post 74, Falmouth road: — Orbitoides and Nummulites.

Highgate, St. Mary Parish: — Orbitoides dispansus; Orbitoides sp.; Textularia; Pulvinulina; Nummulites.

Port Antonio, Slide No. 13: — Globigerina dutertrei, d'Orb.; Globigerina bulloides, d'Orb.; Miliolina seminulum (Linné), also Catadupa; Nummulites; Amphistegina lessonii, d'Orb. (A. hauerii, d'Orb.); Orbitoides fortissii, d'Arch.; Nodosaria; Vaginulina; Orbitoides papyracea, (Boubée); Discorbina.

This bed is Eocene.

Port Antonio, Slide No. 23: — Nummulites sp.; Orbulina universa, d'Orb.; Globigerina bulloides, d'Orb.; Heterostegina sp.; Orbitolites complanata, Lam.

This bed is Eocene.

13. Port Antonio: — Nummulites; Amphistegina lessonii, d'Orb.; Orbitoides fortissii, d'Orb.; Orbitoides papyracea, (Boubée); Nodosaria; Vaginulina.

This is Eocene.

Buff Bay "near Tunnel." (Montpelier Formation at base of Section.) — This limestone contains an abundance of Globigerinidæ, also many Nodosariæ.

Globigerina: — Truncatulina wuellerstorfi, Schwager; Eocene to recent. Nodosaria raphanistrum, Linné; Cretaceous to Tertiary. Nodosaria pauperata, Cretaceous to Tertiary; recent. Nodosaria (D) aciculata, d'Orb. Nodosaria farcimen, (Soldani); Permian to recent.

We suspect this to be a Tertiary limestone, since Truncatulina wuellerstorfi begins with Eocene beds. The Globigerinidæ and Nodosariæ prove nothing here, as their range is so great.

In addition to the localities given, the following have been observed from our own collections.

Port Antonio (Collection No. 13), a foraminiferal marl made up of Nummulinæ and Orbitoides, with one Rotalia-like form.

Flint beds of Dover (Collection No. 36): — (1) Section of flint. Mostly opalescent amorphous groundmass, — a few spicules and one Rotalia-like form. (2) Chalk: Globigerinæ mostly, with several species of Orbitoides. (3) Another chalk, mostly Rotalia-like forms.

Belmont, St. Elizabeth, clear crystalline calcite, in which are outlined many Foraminifera, Orbitoides being the predominating form.

One mile south of Port Antonio, in upper part of Richmond beds grading into Cambridge. Nummulinæ? and Orbitoides.

Flints at foot of Montpelier Hill: — These are incrusted with silicified tests of Orbitoides, Alveolina?, and Miliolidæ, while the interior mass of one flint clearly shows the silicified outlines of these remains.

Concerning these species Bagg comments as follows: —

> "The limestones and flints with numerous Orbitoides must belong to the Eocene period, because this genus Orbitoides though sparingly found in Upper Cretaceous beds did not become prominent until Eocene time, and, furthermore, it did not survive the Miocene age and only a few occur in the Miocene. Its geologic range is as limited as almost any other single genus in the Foraminifera group.
>
> "The species of Orbitoides called *dispansus*, Sowerby, is easily recognized by its internal structure and its external mammillated surface. This species is one of the essential constituents of the Eocene rocks of Scinde and also occurs in the Eocene of Southern Germany and Italy.
>
> "Nummulites is another genus almost equally important, being limited in range to the Tertiary period and rarely found now. We have lately discovered this genus in the Eocene beds of Vicksburg, Mississippi.
>
> "The Globigerina limestones of which 48*b* is a good example, are fine illustrations of a rock composed almost entirely of these microscopic organisms. It is, however, impossible to state with certainty its age upon this occurrence. Since *Globigerina cretacea* seems to be absent from these limestones we presume the rock is to be placed in the Tertiary period."

Nummulinæ, so characteristic of the Eocene of Europe and North Africa, but missing in the Eocene of the United States, except in the Vicksburg formation of Florida and Mississippi, where they have recently been identified by Bagg, have been noted in Jamaica, first by De la Beche, next by Woodward, and more fully identified by T. Rupert Jones,[1] supposedly from the Orbitoidal beds, in association with Orbitoides, and also in the flint bearing beds of the Montpelier formation, which erroneously, as in the case of Orbitoides, owing to the stratigraphic misconception, were referred by Jones[2] and Guppy to the Miocene. Operculinæ are also reported by Jones in the flint of Preston, St. Mary, and Brimmer Hill, associated with Nummulinæ, characteristic localities of the Montpelier beds.

In two papers, Prof. Jones[3] describes the material and gives the localities of certain specimens sent from Jamaica in a manner that, after our personal studies of the island, we found no difficulty in recognizing their true stratigraphic position in the general section. This material and its occurrence as given by him is as follows: —

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[1] See papers of these authors previously cited.

[2] Geol. Magazine, London, 1864, Vol. I. pp. 102, 106.

[3] The Relationship of Certain West Indies and Maltan Strata, etc., by T. Rupert Jones. The Geologist, January, 1864, Vol. VII. No. 73, pp. 104, 105.

1. In a piece of gray flint from the base of the White Limestone at St. Thomas, Jamaica. Numerous Orbitoides, mostly *O. mantelli*, though some may be *O. dispansus*.

2. Orbitoidal limestone, Hopewell, Metcalf. Flint with Orbitoides and Nummulinæ, Orange River, Metcalf.

3. Limestone with Operculinæ and Nummulinæ, and the same silicified, Brimmer Hill, St. Mary.

4. Flint with Operculinæ and Nummulinæ, Preston, St. Mary.

5. Orbitoidal limestone, Carron Hall, St. Mary.

6. Alveolina limestone, Crofts, Clarendon.

7. Orbitulina rock, Vere.

8. A specimen of hard yellowish limestone at Clarendon, largely composed of the Heterosteginæ, and further noted in this Part under the head of Bowden beds.

Of the above list Nos. 1, 2, 3, and 4 are undoubtedly from the flint and chalk beds of the Montpelier formation; No. 5 is probably from the Cambridge beds; No. 6 from the Moneague; No. 7 comes most probably from the Cobre limestone overlying the Bowden beds.

From these collections, 1 to 5 inclusive, he identified *O. mantelli*, mixed with numerous forms referred to *O. dispansus* and *O. fortissii*, associated with Nummulinæ. Jones also says[1] that the "*Orbitoides mantelli* of Morton, of stronger growth than the variety found in Jamaica, Antigua, and Malta, characterizes some of the Tertiary beds of Alabama, Nummulites being absent, it is supposed."[2]

To this statement we might add that *O. mantelli* is especially characteristic of the Vicksburg horizon of the Upper Eocene (now lower Oligocene of Dall) of the Southern United States, and has been identified from this horizon by Dall from our collection from the beds of this age in Costa Rica. According to Bagg, *O. fortissii*, "a typical Eocene form," also occurs in Panama lower down in the Eocene.

Jones, accepting the current stratigraphic conceptions, was misled into the serious error of concluding that these forms, notwithstanding their world-wide habitat, were Miocene in Jamaica. This opinion was largely due to the publications of J. Lechemere Guppy.

Fossils of the Moneague Beds. — The limestones of the Moneague beds abound in moulds of Mollusca. Fossils of this character from

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[1] *Loc. cit.*, p. 105.

[2] Since discovered by Bagg. Letter to author.

Retreat consist of single pieces of a delicate branching, indeterminate coral, a Conus, resembling *C. solidulura* Guppy,[1] a Tellina, and large Tubula casts of a Teredo?

The only fossils from these beds which I have been able to have identified are the Foraminifera, of which Bagg has recognized the following species from Cinnamon Hill: *Orbitoides dispansus*, Sowerby; *Orbitoides* sp. undetermined; *Operculina complanata*, Defr.

Of these species Bagg says that the first is Eocene, and the third rare in the Cretaceous and abundant in the Eocene. He remarks that Brady has said that the "Miocene" of Jamaica contains the latter form. Inasmuch as we have shown that the "Miocene of Jamaica" of previous writers meant anything from Eocene to recent, this determination is of no value. Bagg adds that "This bed is Eocene."

Careful collecting should be made from these beds, although the material is of such a poor character that paleontologists to whom it has been shown consider it too poor for determination. The fossils and the material in which they occur are of comparatively deep water character, — more shallow than the Montpelier, but deeper than the Bowden.

The position of these beds below the Bowden clearly indicates that they antedate the latter in age, and for the present we can only say that their affinities are with the Montpelier beds of Eocene age.

The conditions of subsidence which made the deposition of the Montpelier and Brownstown white limestones possible were undoubtedly sufficiently great to drown the pre-existing littoral faunas of Jamaica; and this epoch ended the old insular life conditions of the earlier epochs and separated it from that of the later and succeeding epochs, which assumed a more cosmopolitan character.

The fossils of this horizon practically embrace all the forms which hitherto have been described by the English paleontologists, from the "White Limestone," the "Yellow Limestone," the "Upper Miocene," "Lower Miocene," "Miocene," and Bowden Beds, by Moore, Etheridge, Duncan, Guppy, and perhaps others, and referred to the Miocene, Upper Miocene, and Lower Miocene age by those writers, and finally placed in the Upper Oligocene by Dall.

In résumé we can now say that the hemera of the Orbitoidal fauna of Jamaica is as follows: Orbitoides have been reported in the Hippurites limestone of the parish of St. Thomas by Barrett, Woodward, Jones, and Etheridge, and we have shown their occurrence in abundance in the

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[1] Quart. Jour. Geol. Soc., Vol. XXII., Pl. XVI. Fig. 1, 1866.

TIME.	SERIES.	FORMATION.	MATERIAL.	FOSSIL REMAINS.	EVENTS.	GEOGRAPHIC CONDITIONS.
Late Pleistocene and Recent.	Coastal.	Bogue Island. Montego. Falmouth. Coast Soboruco. Barbican. Hopewell.	Mangrove mud. Alluvial. Littoral marl. Elevated reef rock. Elevated reef rock. Elevated reef rock.	Marine Mollusca, reef coral, etc. Reef coral. Reef coral. Reef coral.	Successive elevations, aggregating less than 500 feet.	Slight peripheral expansion of area to present outline.
Pliocene.		Manchioneal. Kingston.	Littoral marl. Old aggradational material.	Marine Mollusca, Foraminifera, Brachiopoda.	Subsidence, submerging margins of the island.	Island contracted to back coast borders.
Miocene or Late Oligocene.	Bowden.	May Pen. Bowden.	Impure lime. Conglomerate and marl	Marine Mollusca, Echinoids, simple corals, Foraminifera, and Bryozoa. Same as above, and fresh-water shells.	Submergence by subsidence of the margins of the island.	Contraction of island by subsidence.
Middle Oligocene.		Break.			Mountain folding. Elevations to 10,000 feet or more. Intense erosion of surface and intrusion of "granitoid" rocks.	Area expanded beyond present limits; probable connected Antillean land.
Early Eocene to Early Oligocene.	Oceanic.	Cobre. Moneague. Montpelier. Chapelton. Catadupa.	White limestone and marl. White limestone. White chalk with flints. Yellow-white limestone. Nodular limestone in clay.	A few mollusks and simple corals. Foraminifera and Radiolaria. Mollusca, corals, Echinoids, and Foraminifera.	Rising bottom. Profound oceanic subsidence. Initiation of Montpelier subsidence.	All of island submerged except a few points of highest mountains.
Late Cretaceous.	Blue Mountain.	Richmond. Minho. Ballard. Logie Green. Jerusalem. Frankenfield.	Alternation of clay and sandstone. Volcanic tuffs. Black bituminous shale. Yellow marls. Irregular beds of limestone. Irregularly bedded lavas, tuffs, and conglomerates of hornblende andesites.	A few mollusks and corals. Rudistes, corals, and mollusks. Rudistes, corals, and mollusks. Rudistes, corals, and mollusks.	Erosion and deposition of muddy sediments. Active vulcanism. Erosion and muddy depositions. Irregular deposition during a general period of erosion. Active vulcanism.	Lowering of land by erosion. Volcanic summits rising out of the Mesozoic sea.

Cambridge, Montpelier, and Moneague Eocene formations. They are missing in all subsequent strata.

It is also now apparent that Dall's recent statement,[1] based upon Guppy's material from alleged Miocene beds (Oligocene), to the effect that "*Orbitoides mantelli* has not been found in the West Indian species," is incorrect, and we must accept the occurrence of this species as identified by those eminent authorities, T. Rupert Jones[2] and R. M. Bagg.

Concerning the other Foraminifera of the Cretaceous and Eocene strata it can be said that Alveolina is a genus which elsewhere "begins in the Cenomanian, continues in extraordinary profusion, and becomes a most important rock builder in the Eocene[3] of the Paris Basin, Libyan Desert, and Greece, is also reported by Jones in "Alveolina limestone" from Crofts in the northeast corner of Clarendon, — a locality of the White Limestone which we have not had the opportunity of visiting.

The Orbitoides, Nummulinæ, Alveolina, Operculina, and Globigerinæ are Foraminifera which have been found only in the Blue Mountains, Montpelier, and Cambridge beds of the Cambridge section. These genera, with the exception of Globigerina, which ranges extensively through geologic time, from the early Mesozoic to the present, have their typical and highest development elsewhere in the Vicksburg stage of the Eocene Tertiary. In accordance with Dall's usage, the Vicksburg beds, to which the Montpelier beds are undoubtedly equivalent, are now considered the base of the Oligocene. When we consider the stratigraphic evidence concerning the containing formations, there is no reason to believe that their occurrence in Jamaica is later than in this epoch.

The Mid-Tertiary Antillean revolution, with its mountain making, expansion of land areas, and rearrangement of barriers and enclosures, which closely followed after the Montpelier subsidence, seriously affected the conditions of life and produced changes of environment affecting the molluscan and other faunas of the whole Tropical American region. After this revolution, the littoral mollusca, as it next appears in the Bowden formation, presents new and distinct facies, characterized by the appearance in Jamaican waters of species which also occur on the continental borders, many of which are still living. This fauna constitutes the chief bench mark in the whole system of Jamaican Neo-Tertiaries, just as the Cambridge does for the Eo-Tertiaries.

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[1] Proc. U. S. Nat. Mus., 1896, p. 329.

[2] The Geologist, London, 1864, Vol. VII. pp. 103-105.

[3] Eastman's "Text Book of Paleontology," by Karl A. von Zittell, London, 1896, p. 26.

Fauna of the Bowden Beds. — The Bowden coral fauna was published by Duncan. What is apparently the Bowden molluscan fauna was studied by Carrick Moore,[1] and later by Guppy.[2] Etheridge[3] has also written extensively on the fauna. Most of the English writers except Duncan, in discussing the Miocene fossils, have given no specific localities nor any stratigraphic details concerning their occurrence. Duncan gives Bowden, Vere, and the district of Vere, Clarendon Parish, as the localities of his species of Miocene corals.

Some of these early writers give references which indicate that the original source of their material was a collection of fossils brought over by Barrett in 1862,[4] and deposited in the British Museum. Guppy has also described many species collected by Vendryes, who still lives at Kingston. Moore stated[5] that they came from "some beds which were referred to in the Geologist for 1862, page 373." Upon consulting the volume and article quoted, which is Barrett's original article[6] on the Cretaceous rocks of Southeastern Jamaica, no reference to these beds was found. In the Jamaican Reports, however,[7] Barrett notes that in the gravel at Bowden "are beds of the most perfect Tertiary shells yet known on the island, a list and description of which will be found in the Appendix, after critical examination." This brief note is the only clue to the locality of the numerous molluscan fossils usually discussed by most of the British paleontologists from "The Miocene" and "White Limestone" of Jamaica.

From Barrett's short description, given on previous pages, it will be seen that he clearly recognized the conglomeritic nature of the beds at Bowden, and nowhere speaks of the fossils as occurring in the "White Limestone," or "Yellow Limestone," as they were later made to appear by others. His death prevented his further elucidation of these beds, but the above citations undoubtedly give the locality of the Tertiary fossils collected by him and sent to England, to which Moore, Guppy, Woodward, and Etheridge have alluded, and which is the same as that from which Simpson and Henderson (in 1893–94) and the writer (in 1896) made the abundant collections mentioned in this paper.

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[1] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. pp. 510–513.

[2] In many papers previously cited.

[3] Jamaican Reports, pp. 319–338.

[4] See Quart. Jour. Geol. Soc. London, 1866, Vol. XXII. p. 281.

[5] Ibid., 1863, Vol. XVI. p. 510.

[6] Ibid., 1860, Vol. XVI. p. 381.

[7] *Op. cit.*, pp. 44, 45.

It is not necessary to repeat the details, elsewhere stated in this report, of how the original gravel beds of Barrett at Bowden became the "Yellow Limestones" of Etheridge and Duncan and Wall through their miscorrelation by the latter with the entirely different "Yellow Limestones" of Brown in the western part of the island, which we have described as the Cambridge beds and "White Limestones" of some other writers. By easy stages this error grew into a great chain of misinterpretations. Through Etheridge, Barrett's conglomerates became "an outcrop at the base of the White Limestone";[1] next the "Miocene" and the "Yellow Limestone,"[2] as contradistinguished from the "White Limestone," then the "Miocene Limestone" of Woodward,[3] and finally the White Limestone, in general, of the whole Antillean region. It was in this manner, through literary imitations, that the restricted molluscan fauna of a single bed of Jamaican gravel became the fauna of the White Limestones.

Guppy[4] refers back to the articles above cited, and also to the paper of Duncan and Wall,[5] in which, as we have previously shown, the relations of the beds are erroneously given, and wrongly states that "the formation from which the Mollusca to be described consists of shales, sands, and marls exposed *in several parts* of Jamaica."[6]

Concerning the localities of a few Miocene fossils identical with the Bowden forms which have been accredited to "Clarendon" and "Upper Clarendon," it can be stated that these probably came from a point on the seacoast at Round Hill, near Bath, in the extreme southwest corner of the district of Vere, the fossils of which, collected by Sawkins, were said by him to be "nearly all the same genera and species as those found at Bowden, Port Morant, St. Thomas-in-the-East."[7] The reference to "Upper Clarendon" was no doubt an error originally made by Etheridge in citing the field workers. The only allusion made by the latter concerning this locality was in connection with the occurrence of older formations.

Dall has lately published a paper[8] which belongs to a more recent epoch than the contributions of the class of writers previously mentioned. His information was supplemented by the recent field work of Simpson and Henderson and myself. In this paper he describes Guppy's collections, which are accompanied with no information concerning their locality, except that they were collected by Vendryes. We have made inquiries of Mr. Vendryes, through Professor Duerden, concerning the locality of his collections, and he has stated, in a letter dated October, 1897, that they were made at Bowden.

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[1] Jamaican Reports, p. 311.

[2] Ibid., p. 311.

[3] The Geologist, London, 1862, Vol. V. p. 373.

[4] Quart. Jour. Geol. Soc. London, 1866, Vol. XXII. pp. 281, 282.

[5] Ibid., 1865, Vol. XXI. pp. 1–14.

[6] *Op. cit.*, p. 282.

[7] Jamaican Reports, pp. 162, 163.

[8] Descriptions of Tertiary Fossils from the Antillean Region. Proc. U. S. Nat. Mus., Vol. XIX. No. 1110, Washington, 1896.

It is sufficient to state, as far as the described species of the so called Miocene and Oligocene Mollusca are concerned, that, instead of having wide and general distribution in Jamaica, they are known to occur in only one or two restricted localities, one of which, Bowden, has furnished all the recorded species.

In but few other places in the world are fossils so beautifully preserved, so representative of diverse orders, or so numerous in species, as in the gravels of the Bowden beds at the foot of Captain Baker's hill, Morant Bay. These occur only two or three feet above sea level, in the bluffs of the highway where it starts up the hill. A single barrel of this material, recently collected, has yielded more than three hundred species of marine Mollusca, in addition to land and fresh water species, besides twenty-six species of corals, five species of Foraminifera, and traces of Bryozoa and Echinodermata.

In the Bowden beds an entirely new foraminiferal fauna appears, and one which occurs under entirely different conditions from those of the Montpelier beds, representing for the second time in the Jamaican history a shallow water foraminiferal fauna. These are of large macroscopic texture, are found in the Bowden gravel beds, and are of contemporaneous origin with them. Following is a list of the genera collected by me from this horizon at Bowden, as determined by Bagg: —

Foraminifera. — Haplostiche soldanii (Parker and Jones); abundant in Tertiary. Textularia barrettii (Jones and Parker); Miocene to Recent. Textularia trochus, d'Orb.; Cretaceous to late Tertiary, Recent. Orbiculina adunca (Fichtel and Moll); Miocene to Recent. Orbiculina compressa, d'Orb.; Miocene to Recent. Cristellaria cultrata (Montfort); chiefly Tertiary. Cristellaria cassis (Fichtel and Moll); Cretaceous to Recent. Cristellaria calcar (Linné); Miocene and Pliocene chiefly. Gypsina globulus (Reuss); very abundant in Miocene. Gypsina vesicularis (Parker and Jones); same range as G. globulus. Cuneolina pavonia, d'Orb.; Cretaceous (?). Cuneolina sp.; perhaps new. Vaginulina legumen (Linné); Trias to Recent. Nummulites ramondi, d'Arch., Eocene to Miocene rarely; this is not very abundant. Amphistegina lessonii, d'Orb.; Tertiary and rare Recent. Synonymy, A. vulgaris, A. hauerii, d'Orb.; Miocene.

This bed at Bowden must be Miocene. The material from Bowden, Jamaica, is undoubtedly Miocene.

Concerning these Foraminifera Bagg says: "The Foraminifera from Bowden, Jamaica, are essentially tropical species which existed in rather shallow waters of less than 300 fathoms, while many occurred at depths of only a few fathoms and still exist. I have recognized the species *Orbiculina adunca* in the Pliocene deposits of the Caloosahatchie River, Florida. This species, though ranging throughout the Tertiary period, did not become plentiful until Miocene time. *Cristellaria calcar*, Linné, another shallow water form, is remarkable for its large size, reaching nearly $\frac{3}{16}$ in. in diameter in the Bowden specimens. *Gypsina globulus*, Reuss. This curious little fossil, round, as its name implies, and as large as double B. B. shot, is very abundant in the Bowden material. This is the genus described as Tinoporus, Ceriopora, etc. Professor Brady in the Challenger Report says of this form, and its relative *G. vesicularis*, "Both have been obtained in the fossil condition from the Miocene formation of Austria and Hungary, Malta and Jamaica, and from the Pliocene of Costa Rica, and, according to Parker and Jones, from the Tertiary beds of Palermo, Bordeaux, and San Domingo."

The species *Textularia barretti* is still living in shoal waters off the West Indies. It is a curious type of the genus, being compressed at right angles to the usual plane of compression.

Haplostiche soldani is the form described as *Lituola soldani*, but is now placed by Brady under the genus Haplostiche. It still lives off the West Indies, but was most abundantly developed during the Miocene period.

There are numerous specimens from the Bowden gravel which have an aspect which might be, and probably have been, mistaken for Orbitoides.[1] Jones has also reported Orbitolina from Vere,[2] where other Bowden fossils are found, and from the supposed Pliocene Pteropod marls of Jamaica.

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[1] Jones has said that "Orbitoides have long been, and still sometimes are, mistaken for Nummulinæ, Orbitolites, and Orbitolinæ, — all very different one from another; and even when they are recognized, it is often difficult to get at their specific characters." — The Geologist, 1864, Vol. VII. p. 106.

[2] Ibid., p. 104.

There are also two or three specimens of a large form which are either Operculina or Heterostegina. Jones has reported[1] the latter genus from the same horizon as that of the "shells and corals lately brought to England by L. Barrett, and described by J. Carrick Moore and Duncan," in a collection which was clearly from the Bowden formation.

Bryozoa. — The Bowden gravel bed contains numerous specimens of a species of Lunulites, associated with the corals, Foraminifera, and Mollusca. This form attains a maximum size of half a centimeter. Dall has also reported[2] *Membranipora savorti* Audovon, from the "Oligocene of Jamaica."

In the Bowden beds is a varied fauna of simple corals. These in association with Foraminifera, Bryozoa, Pteropods, and other Mollusca occur in vast quantities in the gravel and marl at the foot of the bluff at Bowden, and sparsely in the marl at Buff Bay. They have also been reported by Duncan from Vere, the Clarendon coast, and from Navy Island off Port Antonio; and erroneously reported from "Upper Clarendon" by other writers.[3]

During our expeditions we made a large collection of corals from the Bowden locality and these have been carefully restudied by Vaughan, who adds several to the number of species. He reports the following species from Bowden: Thysanus excentricus, Duncan; Thysanus elegans, Duncan; Placotrochus costatus, Duncan; Placocyathus barretti, Duncan; Placocyathus moorei, Duncan; Trochocyathus profundus, Duncan; Lithophyllia ponderosa (Duncan), (non Montlivaltia ponderosa, Edwards and Haime); Circophyllia walli, (Duncan); Asterosmilia sp.; Teleiophyllia probably grandis, Duncan; Porites sp. cf. furcata; Porites sp. of the astræoides type, but with larger calices; Madrepora sp.

In addition to the species of coral previously described from Bowden by Duncan, Vaughan notes that our collection "is especially interesting because it contains two determinable species of Porites and one of Madrepora, none of which have previously been described," and "which, if *in situ*, contribute rather important information concerning the conditions under which the Bowden beds were deposited."

Concerning the corals collected by us from the Bowden horizon at Buff Bay, Vaughan reports that "it contains a specimen of *Placocyathus barretti*, Duncan, and an undescribed species of Dendrophyllia."

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[1] The Geologist, 1864, Vol. VII. p. 105.

[2] Proc. U. S. National Museum, Washington, 1896, Vol. XIX. No. 1110, p. 329.

[3] See Appendix to Jamaican Reports.

According to Duncan,[1] the Bowden corals (his Miocene) comprise forms common to the Miocene of Europe and species peculiar to the Indian seas, while many of the genera now exist in the Pacific Ocean. He said that one species of Montlivaltia is found fossil at Travanocore.[2] He also states:[3] "Corals from Vere, Bowden, and Navy Island off Port Antonio have no general resemblance to those from the Eocene and Cretaceous strata, but present the appearance of the common specimens of the various Miocene shales and marls of San Domingo and the European Miocene; and all are absent from the existing coral fauna of the West Indies. The comparative absence of compound corals from the Jamaican Miocene is very remarkable; and equally interesting, in reference to the deep sea nature of a part of the coral fauna, is the abundance of Foraminifera which crowd amongst and fill up the interstices of the specimen."

Etheridge states[4] that twelve of the nineteen species worked out by Duncan are common to the Miocene (old usage) of Jamaica and Europe, while eleven of the species are said to be still living, but Gregory and Vaughan cast doubt upon the validity of Duncan's conclusion, as he seems to have confused species from the elevated reefs with those from entirely different horizons. It may not be out of place to add that this fauna is totally distinct in genera and species from another West Indian "Miocene" coral fauna described by Duncan from Antigua. Duncan has also stated that a majority of these species indicate deep water.[5] This fact seems to be borne out by the studies recorded in the "Three Cruises of the Blake."

It is an important fact that only three closely related compound species of corals, such as composed the elevated and modern reefs of the Caribbean region, were found by me in the Bowden beds, and these may have been pieces of recent beach débris. This indicates that true reef building corals had not made serious appearance in Jamaica at the time of the deposition of these beds. The Bowden corals have been frequently cited as reef making forms.

Moore recognized[6] seventy-one species of marine Mollusca from these beds, twenty-eight of which were alleged to occur in the San Domingo beds, and twelve of which are living in the adjacent seas.

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[1] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. p. 454.

[2] Ibid., p. 456.

[3] Ibid., 1865, Vol. XXI. p. 14.

[4] Jamaican Reports, p. 309.

[5] Quart. Jour. Geol. Soc. London, 1868, Vol. XXIV. p. 12.

[6] Ibid., 1863, Vol. XIX. p. 511.

Guppy has described 250 species of "Tertiary fossils of the West Indian region" without giving definite localities or horizons, but we have reason for believing that a large majority of these come from the Bowden beds. Dall has recently described[1] forty-eight additional species from the "Oligocene of Jamaica," which are all from the Bowden locality.

No detailed list of the molluscan fauna of Bowden as a whole has been made,[2] although such a catalogue would be most important and valuable, for with it the discussion of all great questions concerning the West Indian later Tertiary paleontology would be made intelligible, while now this subject is in a stage of mist and chaos. Dr. Dall has in his hands the material for such a catalogue, and it is sincerely hoped that he will make one at an early day. It is a well known fact that a large percentage of these Bowden forms have persisted through later times and are at present living in West Indian waters, and that deductions concerning the Pliocene or Pleistocene age of the succeeding beds can be made only on the percentage of many forms. Without a census of the Bowden molluscan fauna, it must be evident that all such deductions as have been or will be made concerning this fauna are unstable.

Dall correlates[3] this molluscan fauna with the "Chipola, Tampa, and Chattahoochee horizons of Florida, corresponding to the Aquitanian of France." He also notes the wide occurrence of this fauna in the Antilles, Trinidad, and Curaçoa, and on the mainland of Panama. A large percentage of these forms still exist in the adjacent seas and represent the ancestral conditions of the present life.

No traces of Pteropods were found in my examinations of any of the rocks below the Bowden beds. In the latter numerous specimens of small Pteropods about five millimeters in length appear. In these beds there are also many specimens of a craniate shell attaining a diameter of half a centimeter which may belong to this order. Bagg has kindly identified the species as follows: Hyalæa gibbosa, Rang; Hyalæa limbata, d'Orb.; Hyalæa (Diacria) vendryesiana, Guppy.

The land and fresh water Mollusca of these beds stand out strong and clear, thanks first to the admirable studies of Simpson.[4] He enumerates the following fossil species from the beds at Bowden: Neocyclotus (Ptychocochlis) bakeri, Simpson; Lucidella costata, Simpson; Pleurodonte bowdeniana, Simpson; Thysanophora; Opeas; Succinea.

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[1] Proc. U. S. Nat. Mus., Vol. XIX. pp. 303–331, Washington, 1896.

[2] I have heard that G. F. Harris, British Museum, is now working on one.

[3] Proc. U. S. Nat. Mus., Vol. XIX. p. 304, Washington, 1896.

[4] Distribution of the Land and Fresh Water Mollusks of the West Indian Region and their Evidence with Regard to Past Changes of Land and Sea. By Charles Torrey Simpson. Proc. U. S. Nat. Mus., Vol. XVII. pp. 423–450, Washington, 1894.

In the marginal land derived material of the upper part of the Blue Mountain Series and Cambridge beds, no remains of land or fresh water mollusca have been found, and if they existed in late Cretaceous or early Eocene times, it is singular that no trace of them can be found in beds so peculiarly adapted for their occurrence. Even if they previously existed, their absence in the deep water marine beds of the Montpelier and Moneague beds would be natural, for they are never met with in such formations.

In the Bowden series, however, land shells do appear for the first time, several species having been sorted out of the great fauna of Foraminifera, Bryozoa, Hydroids, corals, and Mollusca of this peculiar littoral formation which occurs in the midst of the great White Limestone Series. Their appearance here fits in beautifully with the facts of the Mid-Tertiary land expansion elsewhere given, and thoroughly satisfies the facts of the present known distribution of their descendants in other islands and in Central America, as elsewhere explained. Simpson has found a probably fossil land shell in the succeeding Cobre limestone of Bog Walk.

A few traces of fish teeth have been found in the Bowden formations.

In résumé, it can be said that the Bowden fauna as a whole marks a most important horizon in Jamaican history, representing the reappearance of molluscan life after the long hiatus intervening since the Cambridge epoch, and presents the beginnings of the littoral fauna which have since prevailed around the border of Jamaica in the later Tertiary, Miocene, and Pliocene-Pleistocene, and recent time.

The Cobre Beds. — The Cobre (White Limestone) which may be a synchronous but deeper water formation than the Bowden beds, is largely composed of Foraminifera mixed rarely with débris of Mollusks, simple corals and Echinoidea. Mollusca are almost entirely missing from this formation, except at its immediate base near Bog Walk village, where many imperfect casts may be found, all of which have a superficial resemblance to the Bowden and later forms. In these beds we found two or three specimens of Echini. The main portion of this limestone is almost entirely foraminiferal.

Our microscopic sections of the white limestone of this formation, from the convict quarry east of Kingston and Bog Walk, show a large number of small Foraminifera of many species, but in which Nummulinæ, Orbitoides, etc., of the Montpelier and lower beds are entirely absent. To this formation belongs the collection of specimens described[1] by William Hill from Mile Gully, Manchester Parish, containing Amphistegina.

Probably this is the limestone largely composed of Heterosteginæ from Clarendon Parish, described by T. Rupert Jones,[2] which he says "corresponds to the same horizon as that of the shells and corals [Bowden] brought to England by Mr. L. Barrett and lately described by Mr. J. Carrick Moore and Dr. Duncan."

Bagg reports as follows upon the Foraminifera of limestones collected from the Cobre formation.

No. 80. Yallahs: *Globigerina bulloides*, d'Orb.; Cretaceous to Recent. Orbulina universa, d'Orb.

The apparent absence of *Globigerina cretacea* makes it very probable that the rock is to be placed somewhere in the Tertiary period, but *Globigerina bulloides* occurs abundantly in many horizons.

No. 58. Rock Quarry, one mile east of Spanish Town: Amphistegina, (also at Bowden); Nodosaria; Globigerina; *Textularia trochus* (also at Bowden); Textularia (2 sp.); Rotalia or Discorbina.

No. 62. Retreat, Clarendon, Operculina (?); Textularia (also at Bowden); Cuneolina (?) (also at Bowden); Gypsina (also at Bowden).

No species of corals have as yet been identified with certainty from the Cobre limestone beds. Only two or three imperfect specimens of what were apparently simple corals were found in our close examination of hundreds of outcrops of this formation, but they were too imperfect for specific identification. They resemble very much the simple forms of the Bowden beds.

Duncan has reported three species from "the hard white limestone" which may have come either from the Cobre formation or the white limestones of the Coastal Series. One of these, *Alveopora dædalæa* is known to occur in formations of later age than the Bowden beds, in Antigua; another, *Cyphastræa costata*, a doubtful species, is said to occur in the Post-Pliocene (presumably Pleistocene) beds of the island of Barbuda.[3] The third, *Astrocœnia decaphylla*, he says, is a Cretaceous coral of Europe. Probably the stratigraphic occurrence of the latter in Jamaica was not properly represented to Duncan, and it may have come from the Cretaceous formations of that island, in which some of the limestone (notably of Clarendon) is as "hard and white" as any of the other white limestones.

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[1] Quart. Jour. Geol. Soc. London, 1891, Vol. XLVII. pp. 248, 249.

[2] *Op. cit.*, pp. 104, 105.

[3] "*Cyphastræa costata*, Duncan. The type from Barbuda is a piece of the small caliced West Indian *Orbicella* — *O. aeropora* Linn. (Gregory) *O. annularis*, Dana, of Pleistocene, late Tertiary or recent age. The other specimen, from Santo Domingo, and labelled *Cyphastræa costata*, is a *Solenastræa*, therefore the name *Cyphastræa costata* must be dropped from coral nomenclature. Gregory's *Cyphastræa costata* are *Orbicella acropora*."— Vaughan.

Fauna of the Pliocene Formations. — In the Pliocene, Manchioneal, and Mulatto River beds of the Coastal Series, we have the first undoubted appearance of the modern reef building compound corals in the Jamaican sequence. In these two localities of supposed Pliocene age, the forms occur sparsely as single heads in the former, and as a thin stratum of true reef rock about one foot thick in the latter.

Vaughan has recognized an *Orbicella*, probably *radiata*, and a *Meandrina* from these beds.

In discussing a species of *Terebratula* reported by Guppy from Trinidad, Etheridge[1] distinctly notes that "none occur in the Tertiary of Jamaica, although careful search was made through the collection." De la Beche says,[2] "At Manchioneal Harbor the white marl contains corals, spines of Echinites and Terebratulæ, besides casts of other shells." Barrett, in a note which was published by Woodward in the "Critic" of February 1, 1863, also noted the occurrence of Terebratulidæ in the new Tertiary of Jamaica.

We were fortunate to find in these beds at Manchioneal two Terebratula forms which have been determined by Schuchert to belong to the genus Liothgrina. Most of the specimens are *L. vitrea*, Borne, and one specimen is probably *L. bartletti*, Dall. The former is not known as a living species in the West Indies, but is a common species of the Pliocene of Sicily.

There is also a single specimen of a large and beautiful *Caviolina*, about one centimeter long, very much resembling the figured specimens from the Pliocene of Italy. From the so called Pteropod marls, which are probably allied in age, Etheridge reports[3] three genera of Pteropods, to wit, *Cleodora*, *Creseis*, and *Cuvieria*. The Manchioneal beds contain but few other molluscan remains, only a few moulds and casts having been found by me. Barrett, who collected more thoroughly, is said to have found sixteen species of recent Mollusca belonging to the surrounding seas in this marl.[4]

The "Pteropod Marls" of Barrett — our Manchioneal beds of supposed Pliocene age — contain still distinct foraminiferal fauna, the species of which, as determined by T. Rupert Jones and W. K. Parker, are nearly all identical with those dredged by Barrett in the adjacent sea at depths which indicated at least 100 fathoms.

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[1] Jamaican Reports, p. 318.

[2] Ibid., p. 181.

[3] Ibid., p. 319.

[4] Ibid., p. 313.

The species determined by Jones and Parker[1] are as follows: Nodosaria raphanus; Nodosaria raphanistrum; Dentalina acicula; Frondicularia complanata; *Cristellaria calcar; *Cristellaria cultrata; Cristellaria rotulata; Cristellaria italica; *Orbitolina (Gypsina) vesicularis; Bulimina ovata; *Lituola (Haplostiche) soldanii; Vertabralina striata; *Cuneolina pavonia; Vagulina acumen; Vagulina striata.

Eight of these species have been found living in the adjacent waters by Barrett. Five of the species (marked *) are the same as those identified by Bagg in the Bowden beds. Those genera which are specially characteristic of the Oceanic White Limestone and Cambridge beds, such as Orbitoides, Nummulinæ, Operculina, Heterostegina, and Amphistegina are absent here,[2] as well as from the Bowden beds.

In the Falmouth beds of the north and south coast of the west end of the island, the third, last, and most recent horizon of abundant well preserved fossil remains of Post-Pliocene Mollusca are met. They include Lucina, Cardium, Arca, Solen, and many other genera of bivalves, and among the Gasteropoda forms of Turbo and Strombus, such as abound off the present coast, and great numbers of a small Bulla, which is especially abundant in similar deposits of Yucatan, Barbuda, and other West Indian localities. This sub-recent or Pleistocene fauna is well worthy of careful study and analysis by those interested in the study of the paleontology of the Mollusca.

Fauna of the Elevated Coral Reefs. — In the elevated reef of the Coastal Series, corals are everywhere found, either as the chief material of the elevated reefs, as previously described, or as single specimens or fragments in the contemporaneous marls.

Vaughan has identified the following species of coral in the various Soboruco collected by us.

"7. Barbican Bay, Jamaica, twenty-five foot reef; Siderastræa radians, (Pallas); Siderastræa siderea, (Ell. and Sol.); Porites porites (Linn.); Orbicella acropora, (Linn.).

"13. Bluff east of Port Antonio, Jamaica; Orbicella acropora (Linn.).

"16. Soboruco, Port Maria, Jamaica: Lower Soboruco; Orbicella acropora, (Linn.); Siderastræa siderea, (Ell. and Sol.).

"38. Tryhall, Jamaica; Lower Soboruco: Orbicella acropora (Linn.).

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[1] British Association Reports, 1863, p. 80.

[2] Noted by Etheridge, Jamaican Reports, p. 313.

"39. Hopewell, lower reef between Lucea and Montego, Jamaica: Meandrina, sp.; Siderastræa radians, (Pallas); Orbicella acropora, (Linn.); Porites porites, (Linn.); Madrepora muricata, Linn., *forma* cervicornis, Lam.

"50. Soboruco cut in railway, Orange Bay, old Soboruco: Orbicella radiata, (Ell. and Sol.).

"54. Soboruco, Runaway Bay: Orbicella acropora, (Linn.).

"71. One mile west of St. Ann Bay; Lower Soboruco: Orbicella acropora, (Linn.); Siderastræa sp.

"93. Corals from stratified limestone, Mulatto Bay, (Manchioneal Beds): Orbicella acropora, (Ell. and Sol.); Orbicella radiata, (Ell. and Sol.); Meandrina, sp.

"Manchioneal Bluff, 'same as other reefs.'"

PART IV.

Geologic and Topographic Evolution of the Island.

In the preceding chapters we have set forth the general geographic features and the details of composition, structure, and paleontology, and arrived at conclusions by whose use the events accompanying the geologic and geographic evolution of the island can be more intelligently reviewed.

Upon the table (page 143) we have summarized this history in a manner that will enable the reader to follow what will now be set forth in detail. A short sketch of the principal events of its history will now be given, including, first, a brief outline of the events, next, an interpretation of their magnitude.

The known history of Jamaica begins with the expiring days of the Cretaceous period. What part the present locus of our island played in the earlier events of the battle between sea and land preceding this epoch cannot at present be stated, but we do know that in late Cretaceous time its crests appeared above the waters, and that in succeeding epochs grew more and more conspicuous.

The vast accumulation of rolled igneous pebble of hornblende-andesites and volcanic tuffs, which constitute the oldest known rocks of Jamaica, prove clearly that in late Cretaceous time volcanic eruptivity was active at or near the island during their formation, while the colonies of peculiar fossils interbedded at intervals in these rocks fix the time of their origin as the latest epochs of the Upper Cretaceous period. Furthermore, the species themselves, their faunal assemblage, and the circular arrangement of the colonies around the nuclei of the Blue Mountain and Clarendon ridges may possibly indicate that there were several centres of this eruption. The débris of this event was enormous. The thickness of that portion which now survives can be assumed to be at least five thousand feet. The former extent and relations of these late Cretaceous volcanic outbreaks in the Antilles is now concealed by the coatings of later formations, but they were not peculiar to Jamaica alone, as shown later in this Report.

The next event in Jamaican history was the degradation of the nucleal volcanic heaps by erosion, — a fact recorded in the sediments of the upper part of the Blue Mountain Series, especially the Richmond beds. The thickness of these sediments, aggregating 1,500 feet or more, attests the existence of a high pre-existing land, and the abundant plant remains they contain show that it was thickly covered with vegetation. The nature of the sediments themselves, which are of impure land-derived material, carbonaceous clays, sandstones of volcanic débris, and beds of the older igneous pebble reassorted, and the scarcity of animal remains, indicate rapid erosion and deposition. The uniform alternations, the wide extent of the formation, and the occasional presence of marine fossils, show that the material was sorted in shallow waters. This fact, together with the presence of a few pebbles of foreign origin, the absence so far as known of any distinct delta or estuarine deposits, and the widespread occurrence of similar formations in the West Indies, suggests the existence in the region at that time of larger land areas than the mere nucleal summits we have described.

There is also evidence that subsidence accompanied this deposition, and that the two events were so compensatory that the depth of bottom did not materially change. These events were also closely followed by folding of the strata, — a process which was repeated at intervals until the close of Miocene time throughout the Antillean region.

The strata of the Richmond beds are not only everywhere folded, but near Lucca, in the western end of the island, they are closely flexed, and are completely overthrown, as shown in the illustration on Plate XXII. The epoch of this folding could be easily assigned to a later disturbance, such as that at the close of the Miocene, were it not for the fact that none of the overlying and succeeding strata exhibit such intensity of disturbance. The latter occur in gentler and more open folds.

ere is also some evidence of unconformable deposition of the later ds upon the Richmond. On the south side of the Clarendon Mounins the Chapelton beds of the Cambridge formation rest directly pon the Minho beds of the Blue Mountain Series, without the interention of the Richmond beds; the Catadupa beds at Catadupa are interpolated between the Richmond and Chapelton beds; at other places, on the north side of the island, the Chapelton beds rest directly upon the Richmond.

Furthermore, the older beds of the Blue Mountain Series, the Cretaceous limestones and Richmond beds, are all turned up together in this older and more complicated system of foldings, and inseparably constitute the summits of the Blue Mountain Ridge, which between the altitude of 3,000 and 7,325 feet now protrude 4,325 feet above all the later Eocene and Oligocene formations. These facts, especially the different nature of the folding, strongly suggest an interruption of sedimentation and a corrugation of the strata after the close of the Richmond deposition period, and also indicate that mountain making movements were operative in Mid-Eocene time, which may have been the initiation of the uplifts, which had far reaching importance in Antillean history, accompanied by active vulcanism in the Isthmian and probably Windward regions. We are not prepared to interpret fully this particular event without further examination of the region. If, on the other hand, this folding did not occur at this particular epoch, then the Richmond beds may mark the initiation of a great subsidence so clearly traceable in the succeeding epoch.

Lime making fossils begin to appear in the upper part of the Richmond shale where the Cambridge beds begin, — such as Foraminifera, corals, and Mollusks, — and the lime they produce has been taken into solution and segregated into masses and strata of nodular limestone, occurring in the shale. These impure limestones of the Cambridge beds represent the transition between the terrigenous littoral deposits of the Richmond and the deep oceanic chalks of the Montpelier epoch, and are a step in the great subsidence that was then progressing. The "Yellow Limestones," like the Richmond beds, are undoubtedly of Eocene age, corresponding to the later portion of that period.

The rapidity with which the impure nodular limestones of the Cambridge grade into Montpelier chalks, composed of Globigerinæ and void of molluscan fossils, indicates that the subsidence, initiated as above stated, continued to profound depths, 1,200 fathoms or more, accompanied in adjacent localities with great deposits of Radiolarian earths.

This subsidence was one of the most important and far-reaching events in all Antillean history as we shall show in our next Part. For present purposes, however, it is best to consider how far it involved the pre-existing land topography of Jamaica. Canyon cuttings through the collar of the limestone plateau which now encircles the peaks of Blue Mountain structure show that the latter extends down to sea level and nearly everywhere out to the present margin of the island. The limestone deposits of this subsidence encrust this mountainous core to a height of 3,000 feet, and hence only the portion of the summits above that altitude could have been dry land when this subsidence was at its maximum. This land, then, was restricted to an area of what is now the upper slopes and summit region of the Blue Mountain ridge proper. The remaining parts of the island, including the limestone plateau and the Clarendon and Jerusalem Mountains, were completely submerged. The culmination of this subsidence can be fixed by the paleontologic evidence at the close of the Eocene period, Vicksburg epoch.

The next event in Jamaican history was the re-elevation of the sea bottom and the restoration of the land area to proportions far beyond its present outline, connecting it with the adjacent island of Haiti on the east and possibly the Central American region to the south of west. This elevation is attested, first, by the shallowing nature of the upper limestone Moneague formations of the Oceanic Series, in which simple corals and Mollusca appear; and, secondly, by the emergence of these strata into land during another period of mountainous folding, accompanied by great laccolithic intrusions of igneous granitoid rocks.

This emergence of the island to beyond its present outline is evident. This emergence brought up with it that portion of the old presubmerged mountainous topography now encrusted by a coating 1,000 feet or more of oceanic chalks. That the land extended still farther beyond its present margins than at present is shown by the truncated termination of the formations of the back coast topography, and the unconformity of the later formations against their eroded bluffs, the submerged benches of the island, and the biologic proof that dissemination of the land Mollusca between the islands took place at this time.[1]

This emergence was dominated by a low east and west fold through the geographic centre of the island, which caused its present elongate ape. This constituted a gently arched openly folded anticlinal strucre, inclining north and south. This broad fold is marked in its urse by numerous short secondary wrinkles or miniature low anticlinal lds, as is so beautifully shown in many places, notably near Catadupa nd Montpelier. (See Figs. 18, 19, 20.)

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[1] Distribution of the Land and Fresh Water Mollusks of the West Indian Region. Proc. U. S. Nat. Mus., Vol. XVII. pp. 423–460, 1894.

Accompanying this uplift was a great intrusion from below of the deep seated granitoid and dioritic rocks we have described. The central location of this mass below the limestone, now so beautifully exposed by subsequent erosion in St. Mary, the metamorphism which the overlying Montpelier beds have suffered, and the numerous dikes protruding from it through the oceanic limestones and Blue Mountain Series, indicate that this laccolith was contemporaneous with this epoch, and corroborate the belief that, if it was not the direct cause, it was at least intimately associated with this Mid-Tertiary (Oligocene?) uplift of Jamaica.

The higher terraces or levels, between 1,000 and 2,100 feet, seem to have been during or immediately following this emergence epoch, and previous to the next subsidence to be described. We shall also show that this event was not peculiarly Jamaican in its effects, but had a wide reaching influence in Antillean and Central American geography.

The next event in Jamaican history was a renewal of subsidence and a contraction of the land to its present back coast borders. This subsidence, recorded in the Bowden formation, involved at its conclusion only the margins of the present island area, which at its beginning was probably expanded beyond its present borders. It was initiated by the deposition of the land derived littorals of Bowden gravels, found only in the north and south coasts of the eastern portions of the island, and probably culminated in the deposits of the shallow marls. The amplitude of this movement was probably less than one third that of the great Montpelier subsidence. The Bowden and Cobre beds encrust the pediments of the island up to a height of less than 300 feet. The land area during this epoch again became insular in character.[1]

Succeeding the Bowden epoch there was another upward movement of the island. The larger portion, which had remained land during the Bowden subsidence, including much of the Limestone Plateau and the

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[1] The probable absence of these formations from the western half of the island, if true, and the immediate east coast if proven after further research, may indicate that the Jamaica-Haiti land connection continued to exist during their deposition, and that the more extensive lands existed to the south and west in the vicinity of the Pedro Banks or beyond.

Blue Mountain ridges, was elevated some 500 feet or more, bringing up with it, not only the present marginal border composed of the new made sediments of the Bowden epoch, but a now slightly submerged area towards the south, which extended at least as far as the present 500 fathom line, embracing the Pedro banks and keys. This upward movement, while accompanied by slight deformation, was less orogenic than those of the preceding epoch, probably representing the last throes of the Antillean uplifts. It is very certain that the large area of Jamaica was expanded during this epoch (late Miocene) beyond its present borders at least as far as the present 500 fathom line.

Accompanying or closely following the time of this elevation in late Miocene or early Pliocene time was a period of great erosion and denudation, which largely produced the minor relief of the surface configuration of to-day. During the Pre-Bowden elevation the headwaters of the marginal drainage of the south coast, which then flowed out to sea across the present submerged banks, were actively engaged in cutting out, as headwater amphitheatres, the embryo embayments of the present Liguanea type of plains, and the older sink-holes in the summit of the limestone arch by dissolving through the soluble limestone. In the Post-Bowden epoch the sink holes were cut downward to the insoluble strata, underlying the limestone, producing the first of the present great interior basins, which also commenced to expand laterally by erosion of their soluble margins. Meanwhile, the coastal drainage rapidly extended interiorward by headwater erosion, and the country adjacent to its lower portions became extensive base-levelled plains, and included then what are now the submerged benches of the island, and which were veneered with the aggradational Kingston formation during a subsequent subsidence. This period of erosion was late Miocene or early Pliocene, corresponding in time almost exactly with the great Pre-Lafayette erosion epoch of the North American continent.

During this late emergence the middle series of terraces (now from 200 to 700 feet high) were cut around the coastward face of the back coast country.

Possibly there was another subsidence in late Pliocene time, — the first of a cycle of epeirogenic oscillations that characterized the later history of the island. The island once more underwent partial subsidence; the pre-eroded coastal plains and base-levelled bights bordering the island became in their seaward extension submerged platforms, while their interior borders constitute deeply indented estuaries at the mouths of the great rivers of the south coast and Montego Bay of the north side. The platforms were covered with littoral formations and the estuaries filled with aggradational débris. This submerged the island to the foot of the back coast country. It clearly took place during the late Pliocene and beginning of Pleistocene time.

The next and last event was the epeirogenic elevation, or series of elevations, which have continued until the present time, restoring to the island the belt of land now forming the fringing coastal border, including the elevated reefs.

The continuity of this uplift may have been interrupted by a minor subsidence in early Pleistocene time. Unfortunately paleontologists have not sufficiently analyzed the West Indian marine faunas to enable us to discriminate between the Pliocene, Pleistocene, and recent faunas, especially the last. Hence the differentiation of the stages of Post-Pliocene chronology is still vague. As the pre-submerged platforms of the preceding epoch of subsidence were brought up within the zone of reef coral growth, the first true coral reefs began to fringe the island and formed outlying and fringing reefs. As elevation progressed, the oldest of these were first raised above the sea into a bench of Soboruco, while new living reefs were installed upon that portion of the submerged platform which the elevation in turn brought up to a position favorable for reef growth. Thus successive reefs were elevated into coastal benches, while living reefs continued to grow in the adjacent waters, as are found to-day. In this manner, as the island was constantly rising, the terraces of reef rock now found at altitudes of 60, 25, and 15 feet, as described in the geologic portion of this paper, were made. Similar living reefs continued to grow as now in the adjacent waters, which in turn may some day be elevated into marginal terraces. Inasmuch as the elevated reefs are made up entirely of living species, there is no reason to assign this elevation to a more remote period than late Pleistocene and recent time.

Accompanying their elevation the lagoonal débris behind the barrier reefs was also converted into low coastal swampy lands, and the streams renewed their channels to the sea across the old alluvial plains. This elevation completed the geographic evolution of Jamaica into the land area it presents to-day.

From the foregoing statements it will be seen that the evolution of Jamaica has resulted from varied processes of land construction, including, first, piling up of volcanic ejecta in the beginning of its history, which we shall not further mention at present; and two kinds of uplifts, orogenic and epeirogenic movements respectively.

These movements have collectively constituted the great oscillations whereby, since the close of Cretaceous time, the land and sea bottom have moved up and down, resulting in the expansion or shrinking of the rerespective areas in harmony with these movements.

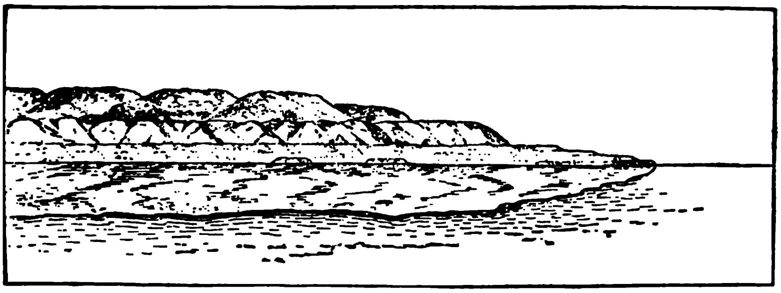

FIGURE 39. Coast Benches, Trelawney.

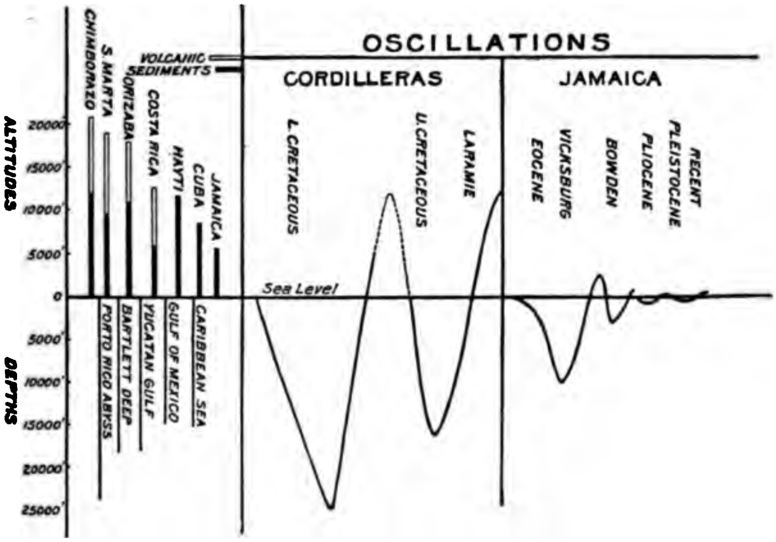

FIGURE 40. — Changes of Level in the West Indian Region.

These oscillations, as summarized upon the accompanying diagram, have comprised three complete cycles of movement, each of which embraced a period of depression and elevation, the downward movement of which may be termed the Montpelier, the Bowden, the Manchioneal, and the Pleistocene subsidences, and the succeeding elevations the Mid-Oligocene, the late Miocene, and the early Pleistocene, or recent elevations respectively. It is interesting to note that these movements are each successively smaller in amplitude than the preceding, like the dying strokes of the pendulum.

The orogenic or mountain folding movements were especially characteristic of the earlier of the middle periods of its history, while the epeirogenic events mark the later stages. The Post-Richmond, Post-Moneague, and Post-Bowden uplifts were all of an orogenic character, but each successively consisting of broader arching and less closely folded deformation. Thus it is that the Richmond beds are closely folded and overthrown, the Cambridge, Montpelier, and Moneague beds arched and gently wrinkled, the Bowden beds only tilted. Collectively, they probably represent the initiation, culmination, and expiration of the great Antillean mountain uplifts. The elevated reefs recording the epeirogenic movements were horizontally elevated without visible deformation.

An interesting fact of the structure of Jamaica, as well as the Antilles in general, are the two lines of orogenic dominant trends, one extending northwest and southeast, and the other east and west. Whether these trends can be each associated with a peculiar effort of mountain making we cannot form definite conclusions at present. It is very probable, however, that all of the structure was originally dependent upon an ancient early Mesozoic orographic uplift or buttress, which had an east and west axis through the Great Antilles and the Guatemala-Chiapas region, the only trace of which is now preserved in the old Post-Paleozoic mountains of the latter region and possibly Western Cuba. It is certain, however, that the earliest movements visible in the present structure of Jamaica had a northwest and southeast trend conformable to the direction of the present Blue Mountain ridge, and conformable to similar trends in the combined coast line of northeast Cuba and Haïti and the outer margin of the Bahama Banks. The later movements have east and west trends (which might be called Antillean), as shown in the secondary axis of the elevated limestone ridges of Jamaica, Cuba, Porto Rico, and the structure of the base of the Yucatan peninsula, the mountains of Eastern Honduras, the Isthmus of Panama, and the Venezuelan coast. It may be well to note here that it is impossible at present to fit into either of these systems of trends — the Bahaman or Antillean — all the Windward Islands or their submarine platforms.

To the physicist who estimates the amplitude of these oscillations there is apparently only one available datum plane, — the position of sea level relative to that portion of the island now protruding above the water. This is an imperfect bench mark, however, for a large portion of the former island surface is now submerged, and sea level may have changed. Fortunately, we have in the geomorphology, stratigraphy, and paleontology of the present land area, and the knowledge of the submarine topography and bathymetric distribution of living marine organisms, important collateral data which give valuable facts for estimates.

The first or great primary oscillation was that embraced in the cycle of the Cambridge-Montpelier descending, and the early Oligocene ascending movement. This subsidence was certainly 3,000 feet, as can still be measured by the height to which the bases of the old pre-existing mountain summits are plastered with its deposits. When we remember that the present land surface of Jamaica is only the crest of a larger Jamaica still submerged, it would be no stretch of the imagination to believe that the movement was from twice to thrice the amount given. In fact, there is very direct evidence which leads us to the latter conclusion.

The purity of the Montpelier chalks and their dominant composition of Globigerinæ would indicate that they were deposited like the deep sea oozes of to-day at depths of 1,200 and 2,300 fathoms. The fact that in the eastern end of the adjacent island of Cuba the stratigraphic and time position of these beds is occupied by Radiolarian earths which are now known to abound from 2,000 to 4,000 fathoms (12,000 to 24,000 feet) justifies us in premising that the Globigerina beds of Jamaica were laid down in very deep waters. It would not be at all unfair to assume the average between the minimum and maximum of the Globigerina and Radiolarian depths as 1,750 fathoms, or over 10,000 feet, as the mean of this subsidence at Jamaica. The assumption of a minimum depth has additional support in the fact that the Jamaican Globigerina deposits were close to the slope of the nucleal islands which persisted as tips of land during this epoch.

The succeeding Post-Montpelier upward movement brought up the bottom not only to sea level (± 10,000 feet), but raised it at least 3,000 feet above it, which would equal an elevation of 13,000 feet. As the highest mountain peaks of Jamaica now stand 4,325 feet above the material deposited in the Montpelier subsidence, they must have reached at the culmination of this elevation altitudes of over 17,000 feet above the sea. As great as these heights may seem, they do not greatly exceed that of the summit of the Sierra de Santa Marta, which now stands beside the Caribbean shore of Colombia, and of other known high peaks like Orizaba and St. Elias adjacent to the Pacific shore lines of our own continent.

So grand a subsidence and elevation as this must surely have left some record in the present submarine topography of the whole region, and we cannot contemplate maps of such phenomena without coming to some very definite opinions which will be elucidated in Part V. Neither could the maximum of elevation have failed to expand the areas of the Antillean lands, and to unite many of the islands or even the mainland together, especially had their geographic areas been greater then than now, which hypothesis seems tenable.

The amplitude of the Bowden subsidence could hardly have exceeded, if it reached, 3,000 feet (500 fathoms). The data for this conclusion are as follows: — The upper and lower limits of the deposition beds of this epoch are now practically visible. While they have, no doubt, been attenuated by erosion and their thickness has not been finally measured, they do not exceed 500 feet in thickness. The lithologic and sedimental character of the beds indicate a rapid gradation from off-shore to moderate oceanic depths. The fundamental beds are gravels, much water worn, embedded in marl, but contain no plant remains or other indications of ultra shallow deposition, although land shells do occur sparingly in them. The fauna could not have lived at depths of over 500 fathoms.

The presence of nearly four hundred species of Mollusca in a single horizon of one of the basement beds at first suggests immediate littoral conditions. Their mode of occurrence in the gravel, however, indicates slightly deeper or off-shore conditions or origin, for had this gravel been near the beach line the delicate shells would have been ground and broken into breccia by wave action, and it is probable that they were too deep to be influenced by any such action. The mollusca are such as live at present at depths of less than 100 fathoms. The several species of Foraminifera, Bryozoa, and corals, especially the last, which are all simple non-reef-building species of the type which Pourtalès has mentioned[1] as having probably lived at an average depth of 450 fathoms, indicate *abyssal* or *continental* deposition. These facts indicate that the basal Bowden beds, now exposed at sea level, were slightly below sea level at the beginning of the Bowden subsidence, and that the amount of the depth must be subtracted from the total thickness of the Bowden to ascertain the true submergence, which could not have exceeded 500 fathoms.

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[1] Cited by Agassiz, "Three Cruises of the Blake," Vol. II. p. 19.

The Post-Bowden (Miocene) emergence equalled the combined thickness of the Bowden beds, the depth of deposition and their present altitude above sea level of about 300 feet, or a total not exceeding 1,000 feet. This movement was to a certain extent orogenic, resulting in deformation by tilting and differential elevation, the rocks being inclined as high as twenty degrees in places.

The amplitude of the Pliocene subsidence, if there was one, judged from the thickness of the Pliocene deposits, could not have exceeded the interval between the present 100 foot contour of the land to about the 100 fathom line of the sea, or a total of 700 feet. It was probably much less. This was sufficient, however, to restrict completely the island to its present insular condition.

The Pleistocene-recent emergence in Jamaica can be measured by the position of the top of the emerged Pliocene rocks above the sea (200 feet), and a conjectural supposition that they were deposited at a depth of over 100 fathoms, or a total of at least 800 feet.

The foregoing estimates platted upon the diagram (Figure 40) are not given with any idea of finality, but as a preliminary contribution — the mere entering wedge — to a subject which future studies will improve, amplify, and correct. They sufficiently approximate the truth to be considered of greater value than mere guesses.

The number and amplitude of these great oscillations, and the radical revolutions in geography which they produced, not only appal the mind by their magnitude, but have taken place with rapidity, — all having practically occurred in the Cenozoic era. They present a flashing panorama of gigantic changes. Yet there is reason to believe that these movements were not catastrophic in character, but of that dignity which accompanies all the great isostatic changes. They are merely further illustrations that geologic time is long, notwithstanding our incapacity for conceiving the fact.

The amplitude of each of these movements, if known with exactness, would be an important key note not only to Jamaican history, but also would throw important light upon the whole of the Tropical American region which participated in them, and of which it is the geographic centre.

PART V.

Relations of the Jamaican Formations to those of Adjacent Regions.

Having given every known evidence of paleontology, geologic structure, and geomorphology bearing upon Jamaican history, and having presented the conclusions in the preceding Part, this work would not be complete without an attempt to point out the extension of the described phenomena throughout the adjacent Great Antilles and other regions of Tropical America, where similar or related geological formations and topographic features of the land and sea should be found. While the facts to be set forth in the present Part make no pretensions to finality or completion, they will be a further contribution to the subject which will assist whoever may hereafter take up and continue these investigations.

I must leave the discussion of the biologic and oceanographic phases of the question to others, and in this place I shall endeavor to discuss only the testimony of the stratigraphy and structural geology, presenting a brief conspectus of the extent throughout the adjacent regions of formations similar to or identical with those found upon the island of Jamaica, together with remarks on the source of the material. In Part VI. I shall review the history of the deformation, including the evidences of elevation, subsidence, and degradation, which often occurred synchronously in different parts of the region, and finally make an inquiry as to their influences upon the present land and submarine configuration of the West Indian region.

The regions with which comparison will be made will be: (1) The Great Antilles proper, including the Virgin Islands and the Bahaman Plateau; (2) The Caribbee Islands; (3) Barbados; (4) The Venezuelan coast of South America, including Trinidad; (5) The Central American region, including the Isthmus of Panama and Yucatan peninsula, and the Guatemala-Chiapas or Tehuantepec Province; (6) The Coastal Plain of Mexico and the United States.

In these presentations I shall be able to show that the Jamaican sequence, so far as it reaches backward in time, is remarkably like that of all the Great Antilles, and may be distinctly termed the Antillean type. This type presents great lithologic variation from that of the peripheral coast lands of the American Mediterranean, yet their relations are harmonious. I shall also be able to show a remarkable difference in some respects between the formation of the Great Antilles and the Caribbee Islands.

In Cuba and Haiti alone of the West Indies (excepting Trinidad, which is as much South American as is Long Island a part of the New England coast) is it at all probable that Pre-Cretaceous or older rocks than in Jamaica are exposed, although theoretically it is even possible that the submerged portions of all the West Indies including Jamaica may have a Paleozoic foundation. Cuba and Haiti it should be remembered, with Porto Rico and the Virgins, are in the main axial line of the Antillean uplift, and it is highly probable that older rocks occur in them, while Jamaica is an outlier or offshoot of this main axis.

The Cuban rocks also contain some mica schists and other classes of rocks which as yet have not been found in Jamaica except in the later débris. Henneken,[1] and perhaps others, have described micaceous schists of supposedly Pre-Cretaceous age in San Domingo. Duchassaing[2] has described a Paleozoic coral (*Favosites Dietzii*) from St. Thomas. Cleve,[3] however, was inclined to believe that this specimen is not native to the island.

Castro and Salterain[4] consider that in Cuba there occurs a considerable range of Pre-Cretaceous rocks, some of which were questionably considered and mapped as Paleozoic. Salterain has referred certain formations, notably in the western province of Pinar del Rio, which the writer has not had opportunity of personally studying, and an area near the city of Trinidad, to the Paleozoic, Triassic, and Jurassic periods.[5]

With the exception of the foregoing, and certain observations of Frazer and Bergt to be noted later concerning the islands of Cuba and Haiti, there are no records of exposures of any Pre-Cretaceous rocks in the West Indies, and while we are willing to grant that they may have occurred, their exposure has been so completely covered by the more recent events of sedimentation, vulcanism, and diastrophism that the interpretable history of the islands may be said to commence with Cretaceous time. The rocks and general section of the Great Antilles all present otherwise a great resemblance to those of Jamaica, as will now be shown.

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[1] On Some Tertiary Deposits of San Domingo. Quart. Jour. Geol. Soc. London, 1853, Vol. IX. p. 115.

[2] Mem. della Acad. dell. Scien. di Torino, 11 ser., Tom. XIX. p. 84, 1860, and Ibid, 1866, Tom. XXIII. p. 199.

[3] Geology of the Northeastern West Indian Islands. By P. T. Cleve. Stockholm, 1871.

[4] Croquis de la Isla de Cuba, 1869–1883.

[5] Lea has also described from near Havana two Brachiopods, *Terebratula poeyana* and *Rhynchonella tayloriana*, which are very similar to certain forms from the Jurassic of Mexico and South America. See Trans. Amer. Phil. Soc., Phila., 1841, Vol. VII. pp. 258–260, Pl. X. Figs. 12 and 13.

Clastic rocks composed of water deposited tuffs and volcanic débris, with occasional Cretaceous fossils of the type of the Blue Mountain Series, constitute the basement formation of the interpretable geologic series in all the Great Antilles as in Jamaica, and form the summit masses of high mountain topography, showing that the present configuration at least has largely been produced since the Cretaceous period.

Rocks of the character of the Blue Mountain Series, which constitute the fundamental formations of Jamaica, have wide occurrence throughout the other Great Antilles, Cuba, San Domingo, and Porto Rico, and the Virgin Islands of St. Thomas, St. John, Tortola, Iost Vandyck, Sandy Key, Guana, Camanoe, Scrub, Mosquito, Prickly Pear, St. James, Dog, Savanna, and Inside Bras; also on the islands of St. Croix and St. Bartholomew,[1] where they constitute the oldest rocks. In some of these localities these rocks of the clastic basement group have not been separated from the overlying Richmond and Cambridge formations.

In Cuba these clastic rocks constitute the high divides of the Oriente, and occur to the westward below the limestones in insular spots as in Jamaica. In addition to the hornblende-andesite gravel which predominates in Jamaica, the Cuban and San Domingo beds contain débris of the older rocks not found in Jamaica.

In the Republic of San Domingo[2] formations analogous to the Blue

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[1] Geology of the Northeastern West Indian Islands. By P. T. Cleve. Stockholm, 1871.

[2] The geology of the island of Haiti or San Domingo has been partially studied by several geologists. These studies have been largely confined to the eastern Republic of San Domingo. So far as we are aware, there is hardly a single published contribution to the geology of the western Republic of Haiti. We have in our possession, however, some important unpublished minor manuscripts by Gabb.

Those who have made researches of the island since 1804 were Schomburgk (1851), Don Manuel Fernandez de Castro (during the Spanish annexation), Henneken (about 1859), Prof. Gabb (about 1870), and the geologists of the United States Commission, W. P. Blake, J. S. Adams, and A. R. Marvine (1871), and L. Gentil Tippenhauer. Of these it may be said that the researches of Schomburgk, Mountain Series have great development where they constitute the highest mountain summits, the Pico del Yaqui, reaching an altitude of 9,684 feet (2,955 meters) according to Schomburgk. They are also probably the nucleal material of the Republic of Haiti, and its two westward extending peninsulas. This formation has been described by Gabb[1] as the Sierra group, and his descriptions in every way coincide with it as it occurs in Jamaica, except that it contains some gravel of different material.

The occurrence of these rocks in the islands to the east of San Domingo is based upon the descriptions given by Cleve in his excellent work on the Northeastern West Indian Islands.[2] He has described, as the "Bluebeache" from St. Thomas,[3] a formation fully 6,000 feet in thickness consisting of stratified conglomerates and tuffs largely made up of hornblendic igneous material, which he says also occurs beneath the white limestone formations, on the north side of Porto Rico,[4] and which he considers probably of Cretaceous age. He has also described the same formation from the Virgin Islands to the eastward.

This formation, which is over 5,000 feet in thickness in Jamaica and 6,000 feet in St. Thomas, is the most important landmark in

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Henneken, Gabb, and Tippenhauer present prospective views of the general geology successively controverting in a more or less degree the previous observations.

Gabb's report on the Geology of San Domingo, notwithstanding its value, presents a confusion of data concerning the Tertiary sequence and the white limestones in general, very similar to that concerning allied formations in Jamaica. After careful study of the work I am of the opinion that he has failed to interpret correctly the stratigraphy of these formations. There can be no doubt that he has confused the two great littorals, the equivalents of the Richmond and Bowden, and classified with the Coast Limestone all the limestone formations from the Montpelier to the elevated reefs inclusive. Furthermore, these errors upon his part have led to some very broad generalizations which are utterly untenable.

Of these writers Gabb has given by far the largest and oftenest quoted report, while Tippenhauer gives the latest and best general summary (Die Insel Haiti, Leipzig, 1893). The recent researches of Bergt, noted on a later page, alleging the possible existence of an older plexus of Pre-Cretaceous rocks were not published at the time of Tippenhauer's contribution. While Tippenhauer's age conclusions are not always reliable, the sequence which he gives of the rocks is the first logical presentation thereof, and presents a remarkable analogy to the general Jamaican sequence as set forth by us, as will be seen by the section on page 172.

[1] Topography and Geology of San Domingo, p. 83, and unpublished manuscript in the library of the U. S. Geological Survey.

[2] Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, 1870.

[3] Geology of the Northeastern West Indian Islands, 1871, p. 4.

[4] Ibid., pp. 14, 15.

GEOLOGIC SEQUENCE OF HAITI, BY TIPPENHAUER.

Age.	Formation.	Material.	Thickness.	Equivalents to Jamaican Section. R. T. Hill.
Post Tertiary.	Alluvium.	Lime, sand, chert, red iron earth, vegetal humus, muck.	Feet. 328	Various coast formations of Jamaica.
	Coast limestone.	Limestone and marl with masses of corals and mollusks.	65.60	Soboruco.
	White marl.	White or yellow marl with some limestone lumps.	295.20	Manchioneal, Pliocene.
Tertiary.	White limestone (Post-Pliocene) = Vicksburg Oligocene.	Chalk marl with red soil.	2,624	Cobre.
		Compact limestone; limestone breccia.		Moneague and Bowden.
		Thin chalky strata with intercalated white marly layers which often contain flints. Thinner sandy strata of limestone mixed with clay.		Montpelier.
	Yellow limestone (Miocene) = Eocene.	Yellow clay and sand; compact yellow limestone alternating with yellow clay and marl. Thin blue strata.	656	Cambridge.
	Eocene conglomerate; later clay strata and sandstone; thinner clay strata.	Green, brown, or dark gray strata between thin layers of fine-grained sandstone (lignite).	984	Richmond beds. Blue Mountain Series; upper part.
Secondary.	Cretaceous Formation.	Yellow marl and clay; yellow-brown limestone; more blue limestone, all containing fossil Hippurites.	656	Antillean, Cretaceous, equivalent to lower part of Blue Mountain Series.
	Metamorphosed Conglomerate.	Metamorphosed clays; sandstones, conglomerates composed of syenite, granite, diorite, much broken.	3,280	
	Plutonic rocks intruding into above.	Syenite, porphyry, granite, and diorite.		

Antillean history, representing as it does the commencement of a consecutive sequence of events from late Cretaceous time to the present. It is clearly the débris of a vast volcanic extrusion which in late Cretaceous time completely obliterated and revolutionized all the antecedent relief. The age of this eruptive epoch is clearly late Cretaceous.

In San Domingo,[1] St. Thomas,[2] and Porto Rico, these formations are associated with limestone beds and Cretaceous fossils in part, resembling in species and faunal associations those of Jamaica, and in part containing species not found in the latter island. In Cuba[3] both the Jamaican and continental types of Cretaceous faunæ are found.

The data seem to point to the fact that the whole region of the Great Antilles proper, including the Virgin Islands, St. Croix, and St. Bartholomew, was the site of active vulcanism in late Cretaceous time.

The extent or outline of the Antillean volcanic disturbance of late Cretaceous time cannot be delineated. It is an important fact that no Cretaceous fossils or formations analogous in age to the Blue Mountain Series are known to occur in the Caribbee Islands proper and Barbados. There is slight evidence, however, that the Cretaceous rocks and fossils of Central America are of the Antillean facies. The sparsely developed Cretaceous formations of Central America known to occur only in the Chiapas-Guatemala district as reported by Sapper,[4] and the San Miguel beds of Costa Rica,[1] are of a clastic nature, and intermixed with volcanic débris, and contain a little studied fauna of Rudistes quite suggestive of the Antillean type. The oldest known formation of Panama is an unfossiliferous andesitic tuff of Pre-Tertiary and probably Cretaceous age.

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[1] From San Domingo, Gabb has reported a serrated oyster, Trigonia, Turritella, Ancillaria, Pugnellus (?), Mactra, Pterocera, Cucullæa, Lima, an Ammonite, and Baculites from beds of limestone in the River Maniel. Tippenhauer (*Op. cit.*, pp. 84, 85) gives the following note on the Cretaceous of San Domingo: "The San Juan valley on Samana, the Pico Gallo on the Central range, the region of Tablasas in the south, are types of this secondary formation. These masses, up to 300 m. thick, form a zone around the highest elevations. Besides vast, compact gray-blue and dark limestone masses, there occur marl and sand strata. The ordinary fossils are Hippurites, Nerinea, and Actæonella. The compact limestone often encloses Radiolites up to seven feet long. In places the limestone has been strongly metamorphosed by the influence of plutonic rock; in such cases it resembles serpentine, is exceedingly dense, and has lost almost all its fossils by obliteration; it is also for the most part whiter."

[2] The beds of St. Thomas, according to Cleve, contain the fossils Nerinæa, Actæonella, Ammonites, Trochus, Pectunculus, Limopsis, Opis, Venus, Astarte, Corbula, etc., of Cretaceous age. Geology of the Northeastern West Indian Islands, 1871, p. 5.

[3] In Cuba the Cretaceous fossils, according to Salterain, are Holectypus, Discoidea, Cassidulus, and Codiopsis; and, according to G. F Matthew, Ostrea, Exogyra, Inoceramus, from a locality in the Cienfuegos road, and a Hippurite limestone composed of Caprinella and Caprotina, corals, a large Oliva, a Conus, an oyster of the type of *O. cristati*, Echini, and sponges from Limones.

[4] Grundzüge der physikalischen Geographie von Guatemala, p. 9.

No Cretaceous formations interbedded in igneous deposits analogous to these are known to exist on the coast of the North American continent north of Tehuantepec, although, as has been shown, active vulcanism was in progress during the Upper Cretaceous period in the vicinity of Austin, Texas, and southwestward. Whether or not this was the most northern extent of the volcanic phenomena which were especially active throughout the Central America, Isthmian, Antillean, Andean, and Venezuelan regions at that time cannot be stated.

The northern portions of the South American continent — Colombia, Venezuela, and the outlying islands of the Venezuelan seaboard — possess Cretaceous faunas of a South American type, including beds of older epochs than those found in Jamaica. Pteroceras, Cerithium, Turritella, Trigonia subcrenulata, Arca, Cardium, and Echinus have been reported by the official Trinidad Survey[2] from Cumana, on the mainland near Trinidad.

Stratified formations of the type of the Richmond beds, composed of impure land derived carbonaceous shales and sandstones grading upward into calcareous beds representing the initiative of the great Mid-Tertiary subsidence, also have wide occurrence in the West Indies, although but few attempts have been made at differentiating them from the preceding group with which they are continuous.

In San Domingo and Haiti, as in Jamaica, this formation undoubtedly has extensive development. It has been clearly described by Gabb,[3] but confused with the equivalents of the Bowden beds. It is most probable that the uptilted coarse sandstones, conglomerates near Bao and Yagui, and the shales into which they grade as described by him, are the equivalents of the Richmond beds. They have a thickness between 1,200 and 1,500 feet. Tippenhauer's[4] description of the Eocene conglomerates of Haiti conforms perfectly with the nature of the lower part of the Blue Mountain Series, and the Richmond beds of Jamaica. Concerning these he says: —

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[1] Geological History of the Isthmus of Panama and Portions of Costa Rica. Based upon a Reconnoissance made for Alexander Agassiz, by Robert T. Hill. Bull. Mus. Comp. Zoöl., Vol. XXVIII. No. 5, 1898, pp. 226, 227.

[2] Report on the Geology of Trinidad, by G. P. Wall and J. G. Sawkins, London, 1860, p. 166.

[3] *Op. cit.*, p. 94.

[4] *Op. cit.*, pp. 85, 86.

> "The Eocene conglomerates consist of sandstones, clay slates, and stratified conglomerates. The latter predominate decidedly. The constituents of nearly all these beds are almost exclusively of volcanic origin, and are to be attributed to the decomposition and erosion of the porphyritic and syenitic rocks, especially the former. The porphyritic constituents have in the main imparted the red color to this formation. The débris forming these conglomerates is granite, especially syenite and porphyry, also trap, more rarely gneiss; they are united by a siliceous cement. Alongside of them are found limestone pebbles, whose blue-gray or black color and Hippurite and Nerinea fossils indicate that they belong to the Jurassic (?) limestone. The texture of the various beds is loose, where no plutonic masses have exerted a hardening influence. The sedimentary origin, however, remains recognizable in the lines of stratification and in the flat rounded pebbles. The strata, varying in thickness from a few inches to several feet, always appear in regular arrangement. At the surface this formation is frequently decomposed into local clays, shining ochres, kaolin, various siliceous stones, agates, amethysts, and quartz. Such surfaces, either high plateaus or mountain crests, always have a dreary red appearance. The clay slates often show a well marked purple color. At the base of this formation occur dark colored clay slates; they seem to extend back into the epoch of the Jurassic limestone. There they also grow more rich in fossils, and show traces of plants, marine shells, and calcspar veins. Lignite beds of small extent lie between the slates. The sandstones bear impressions of leaves and stems. The higher clay slates are light brown or reddish, and form thin beds of friable conglomerates, resting on massive gray sandstones. In the vicinity of eruptive rock the sandstone is hardened, becomes crystalline and transformed into quartz; elsewhere it is soft and friable. The slate has been still more changed by heat, having become porphyritic. When exposed to the air, it crumbles, the sulphur, iron, and lime being separated and forming with the aluminum two differently colored clays, red and gray, used in industry."

In Cuba the bituminous plant-bearing shales of Esperanza and other points in Santa Clara province and in the vicinity of Havana, previously noted by the writer[1] and others, occupy a position below the great White Limestone Series corresponding to that of the Richmond beds. So far as is known the outcrops are not widely developed.

In Porto Rico, the Virgin Islands, and St. Bartholomew, no attempt has been made to separate this formation from the overlying equivalents of the Cambridge beds, or to distinguish it from the Bluebeache, but doubtless future study will reveal its presence there.

[1] Notes on the Geology of the Island of Cuba, Cambridge, 1895, p. 246.

In the islands of Antigua, Guadeloupe, and Martinique, of the Windward Island group, which are quite different in generic structural character from the Antilles and Virgin Islands, there are vast deposits of stratified tuffs which belong to several epochs. The lower portions of these are suggestively like the Richmond beds in arrangement, although entirely different in composition. We are not prepared, however, to assert their identity at present, although there is some evidence of synchronous origin, as some of them in Antigua clearly underlie fossiliferous beds similar to those elsewhere overlying the Richmond. The whole structure of the island of Barbados below the veneering of reef rock is composed of an intensely folded land-derived formation of littoral land-derived shales and sandstones (the Scotland beds) which closely resemble the Richmond Eocene formation of Jamaica and the other localities mentioned, and in our opinion is identical in age with them, as will be shown in a future paper.

The widely distributed occurrence of such beds of land-derived material at the base of the Tertiary in the Great Antilles and Barbados, is suggestive of the existence and destruction of extensive land areas concerning which I can now state but little. Furthermore, these formations are remarkably similar in general character to the synchronous deposits of the continental littoral, as will now be shown.

Along the continental margins of North, Central, and South America there are thick formations of approximately synchronous age which have a remarkable and suggestive lithologic and structural resemblance to the Richmond beds of the Antilles, being composed like them of impure unwashed land derived material accompanied by plant remains and bituminous material, everywhere occurring in uniform wide extending alternations of sands and clays indicative of shallow marginal deposition within the limits of tidal action, and marked by the absence of limestones of organic, oceanic, or other than segregational secondary origin. Of this nature are the lower and by far the greater portion of the Eocene beds of the Southern Coastal Plain of the United States, — the Great Northern Lignite Group of Hilgard, — which extends as far southward as the Tropic of Cancer in Mexico, and the similar formations which characterize the closing days of the Cretaceous and beginning of the Tertiary throughout the great Rocky Mountain front. The lithologic resemblance of the older Tertiaries of the Central American, Isthmian, and Colombian coasts of South America to those of the Antilles is equally striking. In Trinidad and Venezuela the Eocene formation is also represented by a land-derived formation, the Naparima beds, which coincides in character with the Richmond formation of Jamaica.

The wide extent in latest Cretaceous and Eocene time of these impure shallow water land-derived deposits, so alike in sedimentary character, is an evidence of changes of level during these epochs when rapid erosion and deposition were going on. Around the continental margins, except in Panama, the source of the material can be traced to an adjacent back land, but all geologic record of the lands whence the Antillean deposits came are destroyed.

There is also evidence of wide occurrence in the Antilles of stratigraphic horizons corresponding to the Cambridge beds of Jamaica, marking the rapid transition from the underlying land-derived shales into the overlying Oceanic White Limestone deposits of the Montpelier type and characterized by its peculiar invertebrate fauna.

In the islands of Anguilla and St. Bartholomew the shales and conglomerates allied to the Richmond are overlain by or intercalated with limestones and marl beds. The faunas of the two islands, as reported by Cleve,[1] are somewhat different. The fossils of these probable Eocene horizons from Anguilla, as enumerated by Cleve, consist of many species of molluscan genera, only one of which, *Natica phasianelloides*, W. J. G., is also reported from the Richmond beds of Jamaica. These Anguilla beds were originally referred to the Miocene by Guppy.[2] Following the latter author, Cleve, in describing the fossils, referred them to the Miocene. This conclusion was fortified by the identity of the fossils characteristic of the San Fernando beds of Trinidad, which Guppy at that time also considered Miocene. Guppy in his latest papers has referred the San Fernando beds, together with those of Anguilla,[3] to the Eocene, and the latter age must now be accepted for the Anguilla beds, which are worthy of further investigation.

In St. Bartholomew certain beds referred to the Eocene by Cleve[4] and Guppy[5] have a most decided Cambridge aspect. Nearly every fossil genus mentioned from them is identical with those found in the Cambridge and Catadupa beds, including the peculiar gigantic Cerithium, Terebratula, and the Echinoderms Macropneustes and Echinolampus, — genera which were found by me in the Cambridge beds of Jamaica.

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[1] *Op. cit.*, pp. 22–26.

[2] Quart. Jour. Geol. Soc. London, 1866, Vol. XXII. p. 297.

[3] Geol. Magazine, London, September–October, 1874, p. 2.

[4] *Op. cit.*, p. 44.

[5] Geol. Magazine, London, September–October, 1874, p. 2.

There is no evidence that beds equivalent to the Cambridge are represented at all in the other islands of the main chain of the Windward Islands, unless the Orbitoides and Nummulinæ of Antigua, described by Jones[1] from an unknown stratigraphic horizon, belong here. I am disposed to consider them not later than the succeeding Montpelier horizon.

In Barbados and Trinidad it may be possible that the Cambridge horizon is represented by a certain formation characterized by *Nucula schomburki*, which is closely associated with the base of the equivalents of the Montpelier beds next to be described.

In San Domingo, as described by Gabb,[2] the Yaqui shales, like the Richmond shales of Jamaica, grade up into 400 feet of locally varying beds, which, like the Cambridge, are "yellowish or brown or buff color," and like them contain corals and Orbitoides. Many of the fossils noted by Gabb, especially the Orbitoides and Nummulinæ, are similar to those of the upper part of the Cambridge beds of Jamaica, where they grade into the Montpelier beds. Conrad[3] has previously asserted the Eocene character of the fossils of this formation, which Gabb erroneously included in his Miocene.

Tippenhauer[4] has more clearly described the Haitian equivalent of the Cambridge than Gabb. His description of the beds leads me to believe that they are identical with the Cambridge beds of Jamaica in age, composition, thickness, and fossils, thereby indicating a similar geologic history during this epoch in the two islands. His descriptions are as follows: —

> "The yellow limestone lies above the conglomerates and below the white limestone. Its peculiar yellow ochreous color makes it readily recognizable. Bright yellow marls and blue gray clay also occur in this formation. The boundary line between the white and yellow limestone is very indistinct, except that the white limestone is poor in fossils, while the yellow is exceedingly fossiliferous. It is very rich in Foraminifera, Ostrea, and Echini. Instead of the great compact masses of the higher-lying white limestone, the yellow limestone shows series of distinctly stratified thin beds. For the most part these strata consist of yellow, sandy, or clayey marl. In some places the limestone is compact and crystalline. In such cases it forms a fine marble; in others it is impure and verges toward sandstone. The total thickness of this for-

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[1] The Geologist, London, January, 1864, pp. 102–106.

[2] *Op. cit.*, p. 94 *et seq.*

[3] Smithsonian Miscellaneous Collection No. 200, p. 37, and Proc. Phila. Acad. Nat. Sci., 1852, p. 198.

[4] *Op. cit.*, pp. 85–87.

mation may be about 200 meters. The formation of the yellow limestone, essentially marine in character, seems to have been terminated by river-mouth deposits, since its highest strata consist of shells and carbonated clay slates, containing brackish water. At this period the formation must have been almost on a level with the surface of the sea, but after it, during the deposition of the white limestone, there was presumably a great epoch of depression ; the yellow limestone must have descended to considerable depth to allow the formation of 800 meters of white limestone. A remarkable peculiarity becomes apparent at the surface of the yellow limestone. After the primitive forest has been cut down, no other trees grow on it, but only a graminea (*Anatherum bicorne*). This phenomenon is so characteristic that it indicates the boundaries of this formation. Owing to the extraordinary porousness of the white limestone, water readily seeps through it, and, unless carried off by underground flow, it descends until it reaches the impervious clay of the yellow limestone, and there, under appropriate conditions, gushes out of the ground.

"Among the common fossils of this formation are Cardium, Ostrea, Trochus, Natica, Cerithium, Conus, Serpula, Echinocyamus, Echinolampus, Orbitoides, and Corals."

Every detail above noted corresponds exactly with the character of the Cambridge beds of Jamaica.

Formations allied to the deep water Montpelier beds of Vicksburg age (late Eocene of old writers, early Oligocene of Heilprin and Dall) constitute an especially important landmark in Antillean history, and have wide occurrence. White limestones made up of Globigerina chalks or white siliceous deposits composed of Radiolaria occur in Cuba, Haiti, Barbados, and Trinidad. In Barbados the Globigerina chalks grade down into pure Radiolarian earths, constituting with them a related and continuous formation, which in turn overlies the older Eocene Scotland formation, composed of land derived sediments like the Richmond beds, and are folded together with them in the most complete mountain structure. This association of the Globigerina and Radiolarian beds in Barbados establishes the intimate relations of the deposits.

At Baracoa in the northeast part of Cuba, and Port Jérémie, on the north coast of the southeastern peninsula of Haiti, Radiolarian earths occur in great abundance. I was so fortunate in my explorations of Cuba as to ascertain the exact stratigraphic occurrence of these Radiolarian earths unconformably beneath the late or Bowden Oligocene, then called Miocene by Dall.[1] In the light of my later researches in Jamaica,

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[1] Notes on the Geology of the Island of Cuba, Bull. Mus. Comp. Zoöl., Vol. XVI. No. 15, Cambridge, 1895, p. 253, Pl. I. Fig. 5.

I have no hesitation in considering this bed synchronous in age with the Montpelier chalk of Jamaica.

In Cuba foraminiferal white limestones of the Montpelier type have wide extent, especially in the western and central portions of the island, notably in Havana and Matanzas.

The Eocene system of Cuba, as described by Castro,[1] Salterain,[2] and Valentin Peleterro,[3] undoubtedly includes the equivalents of our Cambridge and Montpelier beds. Among the characteristic fossils are *Orbitoides mantelli* and *Aturia zigzag*, Sow., the latter from La Criolla, near Havana, and from the Sierra de Santiago.[4] According to Salterain, this is also the same species as that called *Nautilus cubaensis* by Lea.[5] These fossils occur in a white limestone very much like that of the Montpelier beds of Jamaica, and have wide occurrence.

That the Cambridge and Montpelier beds have extensive development in Haiti and San Domingo there can be no doubt. This the reader can readily ascertain, if, after reading this report, he will peruse the descriptive portions of Gabb's Geology of San Domingo, although Gabb does not differentiate the white limestones of the upland or interior from that of the coast formations, but confuses them together under the head of the Coast Limestone, in the very untenable thesis on pages 103–112. In numerous places in the descriptive portion of his report the upland limestones are described in a manner that leaves no doubt not only as to their existence but also their differentiation into the several kinds we have described from Jamaica and Cuba. He notes in many places the occurrence of Orbitoides, and says,[6] "It has more than once proven of great value to me in distinguishing these limestones from the overlying Post-Pliocene calcareous beds." Furthermore, on page 144 of his report, he speaks of a Nummulite form which is found throughout the Dominican "Miocene from the blue shale at its base to the top of the series." In his unpublished manuscript in the Library of the United States Geological Survey, entitled "Additional Notes on the Topography and Geology of San Domingo," he further comments on the occurrence of the *Nummulinæ* as characteristic of the otherwise unfossiliferous lower Miocene and its discovery in Haiti. From his details there can be no doubt that the Post-Cretaceous sequence of Haiti and Jamaica are identical in lithologic and paleontologic character, consisting of Richmond-like shales at the base with *Orbitoides* passing up into Montpelier-like limestones with *Orbitoides* and *Nummulites*. In the chapter on "The Geology of the Monte Cristo Range," pages 162–173, he shows that the Orbitoidal White Limestone, as in Cuba and Jamaica, occurs to heights of 2,530 feet. This limestone at Monte Cristo is foraminiferal and of great purity, and like the Montpelier of Jamaica does not weather into red soils. It is also interesting to note that in San Domingo as in Jamaica the *Nummulinæ* and *Orbitoides* occur in the limestone, and the latter extends down into the shale.

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[1] Pruebas Paleontologicas, etc.

[2] Apuntes para una Descripcion Fisico Geológica de la Habana y Guanabacoa, Madrid, 1880, pp. 30–40.

[3] Apuntes Geológicos referentes al Itinerario de Sagua de Tanamo a Santa Catalina de Guantanamo. Boletin de la Comision del Mapa Geológica de España, Tomo XX. pp. 89–98, Madrid, 1895.

[4] Salterain, *loc. cit.*, p. 37.

[5] Trans. Am. Phil. Soc., 2d Series, Vol. VII., Plate X. Fig. 15.

[6] Page 96.

Tippenhauer has described the white limestones of Haiti more fully than Gabb, but like the latter refers them to a more recent age. Under the head of the "White Limestone" which he says covers five eighths of the island, he describes several varieties which perfectly conform with the descriptions of the Jamaican rocks. Unfortunately, however, he ncludes the coast limestone or elevated reef rock in this category and assigns the whole to the Post-Pliocene.

Concerning the Haitian Radiolarian beds nothing is known regarding their stratigraphy, the material being known commercially only from St. Jérémie. From the similarity of geological structure and sequence of that end of the island, and in the absence of information to the contrary, we can at least infer that the Radiolarian beds of this locality are closely related to those of Cuba and the Montpelier chalks of Jamaica.

The Radiolarian and Globigerina earths of Barbados have been made the subject of extensive researches by Jukes-Browne and Harrison,[1] Gregory,[2] and others, and the geology of this island has been recently thoroughly restudied by the writer.

The details of this structure are elaborated with great minuteness in the publications of Jukes-Browne and Harrison. With the exception that they referred the Radiolarian earths and the underlying Scotland beds to newer epochs by one stage than that to which I think they belong, their reports are in general correct.

In Trinidad beds of Radiolarian and Globigerina chalks occupy the same relative position above folded terrigenous formations as in Barbados and Jamaica. These beds, variously called San Fernando and Naparima by Guppy, contain the characteristic *Globigerinæ*, *Orbitoides*, and *Nummulinæ* of the Cambridge and Montpelier beds of Jamaica, and in Guppy's latest papers are referred by him to the Eocene,[1] although for many years he placed them in the Miocene. The position of the white Radiolarian marls above a great series of clays and sandstones resembling the Scotland rocks of Barbados (Richmond beds of Jamaica) has been later confirmed by the observations of Harrison.[2]

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[1] Quart. Jour. Geol. Soc. London, 1892, Vol. XLVIII. p. 193.

[2] Paleontology and Physical Geology of the West Indies. Quart. Jour. Geol. Soc. London, 1895, Vol. LI. p. 293.

Extensive deposits of Radiolarian earths occur nowhere, so far as we are aware, adjacent to the eastern side of the American continent. The occurrence of these apparently synchronous oceanic beds in the widely separated West Indian localities of the Antilles, Trinidad, and Barbados, indicate deep water conditions in each of the regions.

The Vicksburg-Jackson formation of the Gulf States Tertiary is in my opinion synchronous with that of the oceanic beds of the Montpelier epoch of the Antillean region, and are probably the northern shallow attenuation of the oceanic beds of the West Indies. They are characterized by the species *Orbitoides mantelli*, and in Florida *Nummulinæ* also occur. Although composed largely of oceanic material they are shallower beds than the Antillean formations. The visible effect of the Antillean subsidence reflected in the sediments of the Tertiaries of our southern coast was to change their character from the non-calcareous nature observable in the Claiborne to more calcareous deposits of the Jackson and Vicksburg beds. In Alabama and Mississippi the Vicksburg beds, with the overlying Jackson, are white limestones, the combined thickness aggregating about 500 feet. In Florida the Vicksburg beds outcrop in the northern portion of the State. Beneath the Pliocene coating of Southern Florida the Vicksburg beds, as exposed by well drillings, have a thickness of 200 feet, and contain the characteristic *Orbitoides* and *Nummulinæ*. Their microscopic nature has not been investigated. These beds are characterized by the three genera of Foraminifera, *Orbitoides mantelli* (the Orbitoides limestone[3]), *Nummulinæ*,[4] and *Milolidæ*,[5] which are so abundant in the lower part of the Montpelier of Jamaica and Southern Mexico.

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[1] Quart. Jour. Geol. Soc. London, 1892, Vol. XLVIII. pp. 519-524.

[2] Quart. Jour. Geol. Soc. London, 1892, Vol. XLVIII. p. 218.

[3] Dall, Bull. 84, U. S. Geological Survey, page 101.

[4] Heilprin, cited by Dall, Bull. 84, U. S. Geological Survey, pages 103, 104.

[5] Ibid., p. 104.

Beds of the Vicksburg horizon have not been discovered between Yucatan and the Mississippi. Agassiz[1] has reported the beds of the Vicksburg epoch as constituting a ridge along the southern peninsula of Yucatan. Orbitoidal and Nummulitic limestones form a belt of strata in Chiapas and Yucatan back of the later marginal coast formations. A. Agassiz's observations, notwithstanding Heilprin's denial, have been confirmed by the more recent explorations of Dr. Karsten, J. Felix, and H, Lenk.[2] These authorities show the existence of Orbitoidal and Nummulitic limestones in the vicinity of the ruins of Palenque and other localities, and prove according to them the existence of marine Eocene strata of the Alpine Nummulitic and Orbitoidal limestone facies in Yucatan, Mexico.

The only known locality of this formation around the margin of the Caribbean is in the uptilted beds at Guallava, Costa Rica, 150 feet above the sea, which Dall has identified from collections made by the writer, as reported in my work on the Isthmus of Panama. In Costa Rica at least, the Vicksburg beds are of an impure non-oceanic nature, occurring as in the Antilles above igneous derived rocks.

Although the Bowden fossils are reported to have wide extent in the tropical region[3] by paleontologists, the formation has not been clearly defined stratigraphically. According to Dall the molluscan element of the fauna is homotaxially equivalent to the Chipola, Tampa, and Chattahoochee beds of Southern Florida, and occurs also in Trinidad and Curaçoa. It also occurs around the continental perimeter along the Carribbean side of the Isthmus of Panama, where the formation has been described by the writer as the Monkey Hill beds[4] of Panama and back of Chiriqui lagoon. There can be little doubt, however, that the sediments of this age have considerable extent along the Talamancan, Panamic, and Colombian coasts of this general Isthmian region.

The equivalents of this formation are known in Cuba, and its fossils from Haiti. It has great development along the north coast of Cuba especially towards the eastern end, where it is composed of the yellow clays and gravel beds called Miocene (after Dall) in the writer's papers on that island,[5] and is well developed at Matanzas, Nuevitas, Gibara, and Baracoa. I now have little doubt, in the light of later experiences, that the medial limestones of my section at the entrance to the great amphitheatre of Matanzas is also of this formation.[1]

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[1] Three Cruises of the Blake, Vol. I.

[2] Neues Jahrbuch für Mineralogie, 1895, Bd. II. pp. 207, 208.

[3] Proc. U. S. Nat. Mus., 1896, Vol. XIX. p. 304.

[4] The Geological History of the Isthmus of Panama, p. 176.

[5] Notes on the Geology of the Island of Cuba, Cambridge, 1895.

From the numerous paleontological descriptions of Duncan, Gabb, Guppy, and others, this formation is the classical "Miocene" of Haiti and San Domingo, although careful search of the writings of all these authors fails to reveal any stratigraphic data concerning it other than that many of the species came from certain beds near Nivajé.

There is also reason to believe that the Bowden beds are progressively more shallow in nature from Jamaica towards Haiti. Gabb there encountered this character of formation in contact with the similar appearing Richmond and Cambridge beds, and confused them together, — a mistake which has been made by nearly all first workers in regions where aggradational terraines of similar composition are in contact without a conspicuous intervening deposit. Gabb himself notes the duplication of sedimentation cycles in succeeding epochs[2] and these very conditions may have confused him in San Domingo, as they have others in Jamaica.

It is probable that they may occur in Antigua and other Windward Islands, but exploration has not sufficiently progressed to justify a positive opinion. Beds of Antigua which we consider of a later age than the Bowden beds of Jamaica, and usually discussed with them under the general head of the Miocene by Guppy, Duncan, and others, may prove to be identical with the Bowden. In these islands the vast formations of sedimentary volcanic tuffs were probably being made during this epoch.

Close studies convince me that these beds are lacking in Barbados, their position being occupied in the latter island by the unconformity between the oceanic (Montpelier) beds and elevated (Pleistocene) reefs during which time land existed there.

According to Dr. Dall the later or true Miocene is unrepresented in the fossil faunas of the West Indies, during which time the island areas may have had greater expansion than at present. He refers all the formations hitherto called Miocene to the Upper Oligocene. It is my opinion that the differentiation of the faunas of these two epochs needs much research. In Antigua and Porto Rico undoubted Miocene exists.

Vast aggradational deposits of the Kingston type similarly laid down on pre-eroded troughs, benches, interior basins, or other erosion surfaces, are present in Haiti upon even a more extended scale than in Jamaica. They are well developed in Cuba. They are probably absent from the Windward Islands so far as I can ascertain and especially Barbuda, Barbados, Martinique, Dominica, and Antigua, which I have especially studied. In Antigua there is some evidence in the configuration of the Pre-Kingston erosion epoch which is still largely submerged. No formation comparable to the Kingston has been recognized on the mainland of Panama. In the Coastal Plain of the United States and Northern Mexico the so called Lafayette formation of McGee and its extension into Arkansas (the Plateau Gravel) and Texas (the Uvalde formation) is identical in method of origin, although of course not continuous in extent with it. These beds are an important landmark in the physical history and relations of the Antillean region.

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[1] Notes on the Geology of the Island of Cuba, Plate I. Fig. 4.

[2] *Op. cit.*, p. 156.

The Manchioneal (Pliocene) marls of Jamaica cannot be positively correlated with other regions, owing to the vagueness of the criteria for determining beds of this age. That marginal Pliocene formations exist in Cuba, Haiti, and Porto Rico is well known, while the beds of Moen, Costa Rica,[1] and certain formations of Trinidad, Guadeloupe, Antigua, and other of the Windward Islands may be contemporaneous. Formations of this age have also been reported as extending far inland towards the foot of the central summits of Tehuantepec.[2] Marine formations of supposed Pliocene age are also extensively developed in Florida and South Carolina. Catalogues of Tropical Pliocene invertebrate faunas are given by Gabb in the Appendix to his San Domingo Report, and of Florida and Yucatan by Heilprin[3] and Dall[4] from Tehuantepec.

Elevated reefs, fossiliferous calcareous marls of the Falmouth type, and aggradational deposits of Pleistocene or later age have wide and extensive development in the marginal regions of Tropical America. These are all connected phenomena dependent for their origin upon the submergence and re-elevation of the pre-existing platforms and benches, and owe their present position to elevations in late geologic time.

The Falmouth formation, composed of clastic shell limestone, principally molluscan, is synchronous in origin with the elevated reefs. Littoral and lagoonal débris and beach wash preserved as marls and white limestones of this character are extensively developed in Haiti and Cuba, and probably San Domingo, having been well described from the last named island by Gabb. The shell formation underlying the coastal swamps of Panama, although having a matrix of land débris, is also of similar age.

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[1] W. M. Gabb, Journ. Acad. Nat. Sci. Phila., 2d Series, Vol. VIII. No. 4, p. 349.

[2] J. W. Spencer, Bull. Geol. Soc. America, 1897, Vol. IX. pp. 13–34.

[3] Proc. Phila. Acad. Nat. Science, December, 1890.

[4] Bull. Geol. Soc. America, 1897, Vol. IX. pp. 13–34.

A. Agassiz has described at length in his chapter on the Florida Reefs[1] the wide extent of somewhat similar formations which constitute the small keys and reefs of Florida,[2] as well as the whole of the eastern and western coasts of the southern end of the peninsula.[3] He has also shown that a large part of the peninsula of Yucatan is composed of similar material.

These formations are also largely developed around some of the Virgin Islands, and the peculiar island of Barbuda, which the writer has recently studied, is composed entirely of similar rock occurring at two well marked levels 5 and 125 feet above the sea.

This material in the Antilles, Virgin Islands, Yucatan, and Barbuda, is characterized by many beautifully preserved Mollusca embedded in a white limestone chalky matrix. A small species of *Bulla*, still living in the adjacent waters, is specially abundant, sometimes almost entirely composing the mass.

The true elevated reefs of Jamaica are related to kindred phenomena in many parts of the West Indian region. The term reef rock in this paper is restricted to those strata which are composed almost entirely of compound coral heads of modern reef building genera, such as *Porites*, *Siderastræa*, *Orbicella*, *Meandrina*, and *Madrepora*, and does not include other white limestones not of unmistakable reef origin. The genera and species of these elevated reefs, with two exceptions in Barbados found one each by Gregory and Vaughan, are all the same as those of the growing reef of the region today. The living reefs have been reconnoitred and described very minutely by A. Agassiz, and he has noted the elevated reefs in numerous places along the Central American coast, the Tortugas, the Great Antilles, Windward Islands, Barbados, and Florida. He has also shown that these reefs were formed on shallow submarine banks of less than fifteen fathoms, and there can be no doubt but they formed the West Indian region during periods of elevation.

Elevated reefs similar to those of Jamaica are known to border a large portion of the island of Cuba. There, as in Jamaica, they occur only in benches immediately adjacent to the sea, nowhere a hundred feet above its level — in fact not over fifty — although the whole of the white limestones of that island rising to heights of 2,000 feet or over, have been erroneously attributed to coralline origin by various writers.[1]

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[1] Three Cruises of the Blake.

[2] Ibid., Vol. I. p. 54.

[3] Ibid., Vol. I. p. 62.

Similar low elevated reefs occur completely around the island of Haiti, as described by Gabb in a manuscript in the library of the United States Geological Survey, which recounts the results of a second visit to the island after his large report on San Domingo had been published, in which he had erroneously attributed all the white limestones of the region to coral reef origin. The writer has seen many of these reefs on the coast of San Domingo, and they are in general analogous to those of Cuba and Jamaica, although the three subsiding stages of the latter island have not been differentiated. Concerning Porto Rico and the Virgin Islands we have no data proving the existence or non-existence of elevated reefs around their borders. According to Cleve's description of the Virgin Islands,[2] and my observations of Barbuda, the geological position of the elevated reefs of the Great Antilles is generally occupied in these islands by the granular white limestone with molluscan remains previously described. Sombrero, as described by Julien,[3] however, is an exceptional locality in this general region, as it is composed of elevated reef rock, the Bulla limestones and lagoonal material. There is some evidence in the reports of McClure[4] and Henry[5] that elevated reefs occur on the island of St. Croix.

The elevated reef phenomena of the Lesser Antilles are varied and peculiar, presenting different aspects in Barbados and on the leeward and windward sides of the Caribbee Islands. On the windward side of the Caribbees true elevated reefs of the modern type are found bordering Desirade, Marie Galante, and Grand Terre-Guadeloupe, as noticed by Maclure in 1817.[6] Here they occur as in the Western Antilles as simple undeformed benches of reef rock standing from six to ten feet above the level of the sea. The reefs of Guadeloupe were described by Duchaissang in 1847,[7] and were considered by him to be recent in age, and synchronous with the upland formations of that island which contain the remains of fossil man.

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[1] Gabb, Crosby, and others.

[2] Cleve, *loc. cit.*, p. 18.

[3] On the Geology of the Key of Sombrero, W. I., Annals of Lyceum of Nat. Hist. of N. Y., Vol. VII. pp. 251-278.

[4] Trans. Phila. Acad. Nat. Sci., 1817, Vol. I. p. 138.

[5] Amer. Journ. Sci., 1839, Vol. XXXV. p. 73.

[6] Jour. Phila. Acad. Nat. Sci., 1817, Vol. I. p. 135.

[7] Bull. Soc. Géol. de France, 2d Series, 1842, Vol. IV. Pt. 2, pp. 1093, 1094.

In Antigua and Porto Rico there is a reef rock entirely different in mode of occurrence, assemblage of species, and lithologic character from the class of modern elevated reefs we have just described, and belongs to an older geologic period, — probably the Miocene or early Pliocene Tertiary. Furthermore, it is evident that these older Antiguan reefs were elevated by orogenic or volcanic uplifts at a period prior to the later epeirogenic elevation of the true modern reefs described.

True elevated reefs — normal unaltered reef rocks raised by epeirogenic elevation to heights not exceeding 100 feet above the sea — do not occur near sea level in the leeward margin of the Caribbee Islands. The main or inner chain of these islands is in general a mass of volcanic débris almost void of sedimentary rocks. In St. Kitts,[1] St. Eustatius,[2] Martinique, Dominica,[3] and Granada,[4] "reef rock" is alleged to be found tilted at high angles interbedded with volcanic débris, and occurring as high as 500 feet above the sea, but we are not able to state whether these are identical with the true elevated reefs.

On the Central American and Panama (western) coasts of the Caribbean Sea, the modern elevated reefs also occur sparsely at Colon and Limon,[5] but not so highly elevated as in the region adjacent to the Windward Passage, standing hardly five feet above the level of the sea. The same may be said of the elevated reefs of Southern Florida and adjacent regions described by Agassiz,[6] where heights of eight feet are recorded.

In the island of Barbados, which geologically belongs neither to the Caribbee nor Antillean type, the modern elevated reefs attain their highest and most perfect development, and rise to exceptional altitudes of over 1,100 feet above sea level or 1,000 feet higher than elsewhere known. This dome-shaped island is composed of a nucleal mass of rocks allied to the Richmond and Montpelier formations, which are covered by a veneering of true reef rock nowhere exceeding one hundred feet in thickness, which extends to the very summit of the island, and presents numerous benches and terraces, — the old surfaces and escarpments of the reefs which have been elevated without local deformation above the adjacent waters, in which similar reefs with the same kinds of escarpments are now growing. The altitudes of these reefs in Barbados are so distinctly greater than those of the rest of the West Indian region that they can be accounted for only on the theory that the synchronous movement which has produced this result was there of much greater amplitude than elsewhere, as will be more fully discussed in Part VI.

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[1] Geology of the Northeastern West Indian Islands, 1871, Stockholm, p. 21.

[2] Maclure, Jour. Acad. Nat. Sci. Phila., Vol. I. Part I. p. 147.

[3] Cleve, *loc. cit.*, p. 45.

[4] Harrison, "The Rocks and Soils of Granada," London, 1897, reports beds of coral sand and mud 150 feet above the sea at extreme north end of the island.

[5] Three Cruises of the Blake, Vol. I.

[6] The Elevated Reefs of Florida, Bull. Mus. Comp. Zool., Vol. XXVIII. No. 2, 1896.

A discussion of the formations of Tropical America would be incomplete without a consideration of the igneous extrusions which, from time to time, have assisted in producing the radical changes in the geography of the land and sea bottom, and broken into the sequence of sedimentary events. Yet there has been so little systematic study of the various volcanic and intrusive rocks that I take up the subject with great diffidence. Since the time of their intrusion is only determinable by their association with fossiliferous sedimentaries, it is evident, in the light of the facts we have given concerning the latter, that we have some data for at least approximating with more accuracy than has hitherto been attempted the history of the vulcanism.

Dr. Persifor Frazer has asserted[1] that there is strong reason to believe that the axial range of the entire islands, and of Cuba, Jamaica, San Domingo, Porto Rico, and the Windward Islands, instead of being igneous extrusions of the Tertiary period, and later, are in reality crystallines of much earlier date, and may not be entirely volcanic.

The considerations which he advances to support his view are as follows: that microscopic analysis "of the rocks which form the nucleus of the spurs of the Sierra Maestra of Cuba shows immense alteration to have taken place, and consequently a very long period to have elapsed; that the complexity of the congeries of rocks forbids the hypothesis of their having been derived from one mass; that the associated characters are those which one finds united in very many Archæan regions throughout the world; that the products of alteration are similar to those in other Archæan districts, etc.; and that the rocks are diabases or diorites with epidote, porphyry, actinolite, felsite, orthofelsite, and porphyry like that of the South Mountain of Southeastern Pennsylvania. Professor Frazer adds that a number of the first petrologists of Europe who have examined his slides are disposed to consider the specimens of not later than Paleozoic age, while none are willing to deny that they may be earlier.

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[1] British Association for the Advancement of Science, Bath, 1888, pp. 654, 655.

While failing to see on what ground Dr. Frazer extended his conclusions, based upon examination of a single locality in Cuba, to Jamaica, Porto Rico, and the Windward Islands, it may be possible that some of the rocks of the Sierra Maestra range of Cuba are of a Pre-Cretaceous age, although Kimball has shown that the diorites have overflown the Tertiary. Personally, I have failed to find any Pre-Cretaceous crystallines in the localities cited.

Dr. W. Bergt has also strongly advocated the existence of an Archæan plexus at the foundation of San Domingo,[1] another of the Great Antilles. Unfortunately, while his argument is strong, like Frazer's it is largely hypothetical, and not founded upon extended field work. The substance of his conclusions is as follows.

Bergt had before him the following rocks from the southern and southwestern parts of San Domingo: — Crystalline schists: hornblende gneiss; pyroxene granulite; fine-grained typical hornblende schist; chloritic hornblende schist, thin laminated, phyllite-like, folded; garnet amphibolite, augite-bearing, eclogite-like; chloritic schist, etc.

Older eruptive rocks: normal mica granites, having the appearance both of mountain granite and vein granite; protegene granites with the most distinct evidences of pressure; hornblende granites, even macroscopically so rich in large quartz grains that it is impossible to confound them with syenite; syenite subordinate; diorite, quartz-diorite, "Bluebeache"; diabase; quartz-diabase; picrite, olivine rock, serpentine.

Younger eruptive rocks: basalts in doleritic, anamesitic, and basaltic development, the latter compact and of the nature of a finely porous lava; andesites; on the small island of Alta Vela also trachytes.

He concludes that, "while according to Gabb, San Domingo forms an exception, showing none but young eruptive rocks with very old appearance, the above series shows quite normally the well known petrographic and geologic contrast between older and younger eruptive rocks. The eruptive rocks designated above as 'older' differ plainly by their state of preservation, by transpositions and new mineral formations, from the volcanic rocks; they do not even resemble the transition rocks distributed all over America (propylites, Andes diorites, etc.)."

Bergt also concludes that the older eruptive rocks of San Domingo are not the causes of the mountain movements, but, on the contrary, were themselves subjected to such movements, and bear the traces of them in the form of so called dynamometamorphic phenomena; "accordingly they have to be regarded as 'older' until their younger age has been unassailably demonstrated, which is hardly to be expected. The crystalline schists, the last of which might be given considerably greater fulness by collections and observations not merely occasionally, but systematically, bear in no wise the character of contact metamorphism; they have to be regarded as normal Archæan rocks, though, like the older massive rocks, they are in part altered by mountain pressure and folded on a small scale."

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[1] On the Geology of San Domingo, by Dr. W. Bergt. Sitzungsberichte und Abhandlungen der naturwissenschaftlichen Gesellschaft Isis in Dresden, Jahrgang 1897, Juli bis December, Dresden, 1898, pp. 1-7.

Thus, according to Bergt, in San Domingo, besides the younger strata of the Cretaceous and the Tertiary, as the bed rock, there is possibly Archæan plexus.

Bergt and Frazer's conclusions, as far as they apply to Santo Domingo and Cuba, may be correct, for there are other reasons for believing that here and there in the main Antillean chain there are evidences of a Pre-Cretaceous buttress, but there is absolutely no stratigraphic evidence as yet unearthed to warrant the assertions that similar rocks occur in Jamaica, Porto Rico, or the Windward Islands, where as yet no such rocks have been found, although, except in the last named, the clastic and terrigenous nature of the basement exposures certainly indicate the pre-existence of rock masses of older age than those now known *in situ*. The younger eruptive rocks of San Domingo enumerated by Bergt are most probably of Cretaceous and Tertiary age.

Omitting from further consideration the Pre-Cretaceous crystallines, the interpretable volcanic phenomena of the West Indian Islands and the bordering continental lands may be classified for historical purposes into the following time categories: —

1. Regions where there are no visible signs of vulcanism: Eastern Coastal Plain of the United States, Bahamas, Barbados.

2. Regions where vulcanism existed prior to the beginnings of the later Mesozoic: The Cordilleras of North America, Guatemala, Oaxaca, and Andes, and possibly Cuba and Haiti.

3. Regions in which vulcanism was greatest in late Cretaceous and early Tertiary time: Mexican Plateau, Western Coastal Plain, Panama, north coast of South America, Great Antilles.

4. Regions where vulcanism was active in middle Tertiary time, since which it has been quiescent: Panama, north coast of South America, and Antilles.

5. Regions of recent volcanic activity: Southern Mexico, Central America, Northern Andes, and Caribbee Islands in part.

1. There is no evidence that vulcanism has in any way affected the Atlantic Coastal Plain east of the Sabine within the periods of geologic history bearing upon our problems, and hence the northern border region of the American Mediterranean may be considered as having been beyond the zones of volcanic disturbances affecting the Caribbean region.

2. Vulcanism in Cretaceous time undoubtedly affected all the peripheral regions of the American Méditerranean except the Coastal Plain of the Gulf, including the Great Antilles and Virgin Islands, in which detrital igneous rocks similar to those we have described as constituting the oldest formations of Jamaica occur under similar conditions. I have seen these old Cretaceous igneous rocks in Cuba, Gabb has described them from San Domingo, and Cleve has pointed out their wide extent in Porto Rico, the Virgin Islands, and St. Bartholomew. In all these Antillean localities, as in Jamaica, the rocks are of a hornblendic nature, occurring largely as conglomerate and tuffs. In fact, the closing days of the Cretaceous were essentially marked by vulcanism in the Great Antilles. In my report upon Panama I have shown that an old rhyolitic or andesitic tuff of probable Cretaceous age, but not hornblendic, there constitutes the oldest discovered formation.

The occurrence of vulcanism in Cretaceous time in the Andean and Central American region has been shown by many writers. In the Cordilleras and plateaux of Northern Mexico the closing days of the Cretaceous were marked by vast extrusions of volcanic rocks, while volcanic action also sparsely occurred in Trans-Pecos, Texas, and perhaps as far north as Little Rock, along the interior margin of the Coastal Plain during this epoch.

In Eocene time vulcanism was especially violent in the Isthmian, Central American, and Colombian regions, and along the south margin of the Mexican Plateau. The volcanoes of the Caribbee Islands were also most probably active in this period.

There is no evidence that vulcanism occurred in the Antilles or Virgin Islands during the Eocene epoch. On the other hand, all data tend to show that the great eruptive activity of Cretaceous time in the Antilles was followed by epochs essentially marked by placid sedimentation.

The chief Panamic eruptions ceased at or soon after the close of the Eocene, although vulcanism continued in the adjacent Costa Rican and Andean provinces, and along the Mexican volcanic belt, until the present time. On the eastern slope of Costa Rica the Vicksburg fossils of the Guallava formation are interbedded with contemporaneous basic eruptive débris.

Some time during the middle of the Tertiary time — probably between the Vicksburg and Bowden epochs, as we have elsewhere shown — the great intrusion of granitoid and dioritic porphyritic rocks occurred in Jamaica. The dioritic dikes were probably slightly subsequent to the granitoids in sequence, but they are both so intimately associated as to be practically inseparable, and hence may for discussion be considered as a unit. There is little evidence, excepting in the case of the Low Layton basalt, that the igneous rocks of this epoch ever protruded to the surface in Jamaica although they may have done so elsewhere. In Cuba there is evidence presented by Kimball[1] that eruptive diorites overflowed the old Eocene limestones (called corallines by him) of the Sierra Maestra. In the vicinity of Havana the Vicksburg limestones are also cut by Tertiary intrusives.

There is abundant evidence that the Mid-Tertiary vulcanism was far reaching in extent and affected all the Great Antilles, Virgin Islands, Yucatan, Costa Rica, and the Panamic, Colombian, and Venezuelan coasts of the Caribbean. A brief outline of the distribution of these phenomena on the mainland has already been presented in my Panama report.[2] Kimball[3] has described with considerable detail their occurrence on the Santiago coast of Cuba. Descriptions of San Domingo by Gabb,[4] and of Porto Rico, the Virgin Islands, and St. Bartholomew by Cleve,[5] also confirm this opinion. Rocks of this general age also occur in St. Martin, Burks, Coopers, Georges, Round Rock, St. Croix, St. Thomas, Tortolu, and Salt Islands. Cleve doubtfully refers them to the Cretaceous or Eocene; but after reading his observations in the light of our own researches, there can hardly be the least doubt that they are of the same age as the similar phenomena of the Antilles.

With the possible exception of the Low Layton stock of Jamaica, which may or may not have been an accompanying event, these rocks represent the last indications of vulcanism in the Great Antilles and Virgins — where there is no evidence of igneous activity — in the subsequent epochs of late Miocene, Pliocene, Pleistocene, or recent time.

The Caribbee Islands constitute a unique and peculiar volcanic province, the discussion of which, with their general phenomena, can now be briefly considered. To those who first look at the map and have not considered their minute geology, the Lesser Antilles, extending across the east end of the Caribbean from Porto Rico to South America appear as the members of a kindred archipelago. The Virgin Islands at the north are Antillean, while all south of Grenada are South American in natural relations. Barbados may also be distinctly related to the latter category. Even after detaching these termini the remaining islands of the archipelago lying between the Anegada Passage and Tobago, constituting the Caribbee group, present almost as complicated compositions. Some of the northern islands, such as Santa Cruz and St. Bartholomew, are also Antillean in structure, and were it not for the deep Anegada Passage, which almost severs the latter from the submerged platform of the Antilles and their presence on a similar platform at the north end of the Windward Channel, they might probably be considered as Antillean.

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[1] Amer. Jour. Sci., Vol. XXVIII. pp. 419, December, 1884.

[2] *Loc. cit.*, p. 251.

[3] *Loc. cit.*, pp. 416, 417.

[4] Geology of San Domingo, p. 88.

[5] *Loc. cit.*, p. 47.

The Caribbee chain, however, south of the Anegada Channel and north of Trinidad, constitutes a distinct geographic and geologic type, which may be classified by composition into three general sub-types as follows: (1) Volcanic islands composed entirely of igneous material; (2) Islands composed entirely of organic oceanic sedimentary débris; and (3) Compound islands, with a higher summit region of volcanic rocks of the first mentioned class, with added areas or benches of sedimentary rocks. These three types are exemplified in Martinique, Barbuda, and Antigua.

The Caribbee chain is divisible into two parallel belts extending the length of the archipelago. The innermost of these, facing the Caribbean, including Saba, St. Eustatius, St. Christopher, Nevis, Montserrat, Basse Terre, Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines, and Grenada, are composed almost entirely of purely volcanic summits. These islands constitute the newest and highest summits of the Windward chain, attaining heights approximating 4,000 feet in all the islands mentioned except the two most northern, Saba and St. Eustatius, which rise to 2,820 and 1,950 feet respectively, and the Grenadines.

The eastern belt, composed of the sedimentary and compound type, includes Sombrero, Dog, Anguilla, St. Martin, St. Bartholomew, Barbuda, Antigua, the Grande Terre of Guadeloupe, Marie Galante, and Desirade.

Barbados perhaps belongs in a class entirely by itself, lying to the eastward of the chains mentioned.

The arrangement of the islands as borne out by the stratigraphy shows that the axis of volcanic extrusion was the main chain, or belt of islands on the Caribbean side, and that the other islands of organic accumulation represent portions of the windward sea bottom which was brought up by uplifts of the main chain.

This main or interior chain is composed of piled up volcanic débris, and upon the islands of Guadeloupe and St. Vincent there have been active volcanic eruptions in historic time, 1797 in the former and 1812 in the latter. Soufrières, hot springs, etc., show that this activity is only slumberingly quiescent in nearly all these islands. Besides most of them still possess upon their summits one or more true craters, while Saba and St. Eustatius are composed of simple crater cones now quiescent. While these facts attest recent eruptivity in the islands, there is much evidence presaging the conclusion that the present vulcanism is merely the survival of that which began much earlier in geologic history.

The configuration and structure show that their history extends back to considerable antiquity. In the first place while the protuberance of all these islands is largely due to extrusive piling up, the present detailed configuration expressed in steep coastal bluffs, benches, slopes, and canyons, is produced by erosion, which has required considerable time for development. True crater shapes, except in St. Eustatius and St. Christopher, are exceptional, and are merely secondary summit features in the other islands, occurring parasitically upon masses of old eroded volcanic débris reaching a height of 4,000 feet. Secondly, they are all composed largely of vast piles of old tuffs and trachytic débris of many eruptive epochs, like the volcanic heights of the Costa Rican plateau, which indicate long continuation of the volcanism since comparatively remote geologic epochs, reaching back most probably to the Eocene time.

In St. Christopher, St. Eustatius, Guadeloupe, Martinique, St. Lucia, and Granada, disturbed fossiliferous beds of Pleistocene or recent age are found interbedded in volcanic débris of the lower slopes at altitudes of two or three hundred feet above the sea, showing that uplifting as well as extrusion has in part produced the present eminences, and that vulcanism existed in Pleistocene time.

The fossils mentioned are hardly older than Pliocene, and are most probably Pleistocene, and their border-like position shows that the greater mass of the islands were ejected in previous epochs.

So much for the main chain of the Caribbees considered by themselves, but the eastern belt, of the compound type, owe their present position above sea level to the orogenic uplifts which affected the Caribbean area in later geologic time. Guadeloupe and Antigua are the two islands which throw the greatest light upon the age of the vulcanism of the Caribbees.

In Antigua the older massive volcanic rocks constitute a high mountainous region on the south side of the island, while to the northward for miles these are overlapped by a vast thickness of stratified tuffs, evidently the ejecta from the vents of which the massives are the remnantal stocks. This material must be thousands of feet in thickness. It contains beds of thin lime deposits of marine origin, including a bed of older massive consolidated crystalline limestone less than ten feet in thickness, and an old coral reef. Towards the north end of the island the tuffs are overlain by conglomerates grading up into chalk marls with fossil Mollusca of possible Miocene age. In the tuffs there are also beds of chert with vast quantities of fossil wood, land shells, and silicified reef building corals (but no reef rock), which also extend into the marls. Finally there is a small area of elevated reef rock. Of these stratified formations none in my opinion, except of the Orbitoidal crystalline limestone, can be of older age than Pliocene or late Miocene. The latter may possibly be Vicksburg — an opinion based upon the occurrence therein of Orbitoides and Nummulinæ, described by T. Rupert Jones. Upon the erroneous correlation of others he referred these beds to the Miocene, but they are older in age than the Bowden beds of Jamaica "Miocene" with which they have been confused by many writers. These facts show that the volcanic tuffs of Antigua were being formed before the Vicksburg epoch, and that the Caribbean vulcanism was then active.

In Guadeloupe we have somewhat similar evidence concerning the evolution of the volcanic range and the mass of sedimentaries. This island is composed of two parts of about equal area, separated by a shallow creek, Rivière Salée. The most western of these islets (Basse Terre) is a typical volcanic pile of the main Caribbee chain, and is thoroughly mountainous. The most eastern area, Grande Terre, is an elevated cut plain, composed of sedimentary formations of Pleistocene age underlain by a platform of volcanic tuffs, etc., derived from the volcanic débris of Basse Terre. Still to the eastward of Grande Terre is the small island of Desirade, composed entirely of organic material, which, with several other islets, stands above a shallow submerged platform extending out from the south east end of Grande Terre and Basse Terre. To the southward of Grande Terre is the island of Marie Galante. This island is of the same topographic and geologic type as Grande Terre.

Owing to an outbreak of yellow fever the writer's studies of these Gaudeloupean islands were limited to the briefest reconnoissance of their general features as above enumerated, but they were sufficient to warrant the deduction that the following details of the geology as set forth by Duchassaing were in general correct.[1]

These beds consist of three formations, the oldest of which are fossiliferous tuffs called by Jones[2] and Duchassaing the "Pierre à ravets" and "sables volcaniques remaniés par la mer." This is composed of yellow tuff very similar to the oldest stratified rocks of Antigua, with few fossils, and the sands contain three species of Mollusca which Cleve asserts with the enclosing strata greatly resemble the Eocene beds of St. Bartholomew.[3] Above these beds of sedimentated igneous material there is a hard ringing limestone containing Terebratulæ. Still above the latter, and constituting the surface formation of most of the Grande Terre are tufaceous marls very much resembling those of Antigua, containing Foraminifera, Lunulites, and many Mollusks, which Mr. Duchaissaing considered to be "older Pliocene in age." In these beds also occur three species of Echini which were not considered as living in the adjacent waters. The latter beds at oldest cannot antedate the Bowden or late Oligocene. Above these in places are non-marine deposits of land wash in which were found the famous human remains, and which also contain many fossil species of land shells.

The next and latest formation is the "Formation Madréporique" of Duchaissaing. This is true elevated reef rock or Soboruco, and borders all the coasts of Grande Terre as well as constitutes the outlying islands of Marie Galante and Desirade.[4]

These formations of Eocene and later age all overlie the detrital tuffs of the old volcanoes of the Caribbee chain, and demonstrate the antiquity of the vulcanism.

These facts above presented lead me to the following conclusions concerning the Caribbee Islands. Their geomorphology is entirely different from that of the Antillean province except in those features on the Windward side recording the events of the last epochs of geologic time. No similar phenomena indicating harmony of elevation and submergence in previous epochs can be made out. The cut plains of the north half of Antigua and the Grande Terre of Guadeloupe clearly show that regional elevations have taken place after the close of Miocene time, followed by erosion epochs and a Pliocene or early Pleistocene subsidence somewhat analogous to the Lafayette events. The bordering reefs formed on the rising platforms at Marie Galante and Desirade, and the double terrace structure of Barbuda show that these islands participated in the general Post-Pleistocene elevation of all the West Indies. Prior to the latest Miocene the details of composition and history were entirely dissimilar, and unlike the events of Eocene and Oligocene history of the Great Antilles.

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[1] Bull. Soc. Géol. France, 2d Ser., 1847, Vol. IV. Part II. pp. 1098–1100, and 2d Ser., 1855, Vol. XII. pp. 753-757.

[2] Histoire physique des Antilles française, Paris, 1822.

[3] *Op. cit.*, p. 44.

[4] The reef formation of these two islands was also described by Maclure in 1817. See Journ. Phila. Acad. Nat. Sci., Vol. I. p. 135.

During all these epochs from the Eocene to the present the volcanoes of the Caribbee chain have been piling up the vast heaps of stratified tuff that form not only the eminences but much of the extensive submarine platforms of the region.

The island of Barbados, standing 125 miles east of the main Windward circle, and separated from it by over 2,000 fathoms of water, is entirely unlike the Antillean, Windward, or Central American provinces in history and geomorphology. It has no known volcanic rocks.

These facts concerning the geology of the Lesser Antilles clearly show that piling up of volcanic material began there as far back as the Eocene epoch, and that the islands have participated in the later epeirogenic movements of Pleistocene or recent time. Hence we may conclude: —

1. The Windward Islands represent a distinct volcanic province, dissimilar in lithologic composition from the older volcanic phenomena of the Antillean province, and somewhat similar to the volcanic summits of Central America.
2. Their visible history dates back at least as far as Eocene time, and their periods of greater eruptivity ceased in the Pleistocene.

PART VI.

Changes of Physiography in Tropical America, bearing upon the History of the West Indian Islands.

The interpretation of the present configuration and history of the Antillean and Central American regions is a difficult task, and involves the analysis of many groups of data, embracing several distinct fields of research. Biology, paleontology, oceanography, structural geology, diastrophism, orogeny, and physical geography, must all be considered. The past and present distribution of life of all orders, both land and marine, their paleontologic history, the part which the débris of their skeletons, extracted from the liquid sea, has played in accumulating strata upon the submerged slopes and bottoms or building coral reefs are also important factors. The possibilities of the great Equatorial current and Gulf Stream, as carriers of sediment, corrosive agents, and the effect on the distribution of lime-making organisms is also a most important consideration.

There are several important conditions which make all attempts at final interpretation of Antillean and Tropical American history more or less hypothetical. The first of these is the fact that the submarine configuration suggests that large areas of land now submerged may have existed, not only in the immediate basins of the American Mediterranean, but also in the Atlantic and Pacific waters off the present continental borders. These submerged areas are now so covered with accumulations of organic and oceanic débris that their geologic composition can never be approximated even by soundings. Much of the older sedimentary strata of the present land masses have also been as completely concealed by burial beneath vast accumulations of volcanic ejecta, especially in Central America, the southern end of the Mexican Plateau, and the Caribbee Islands.

Notwithstanding the incompleteness of the record, the general configuration, and the geologic structure and paleontology of the land areas, and the distribution of the present life of the land and sea, afford much data of a fragmentary nature which can be so placed together as to throw some light upon the geologic evolution of the region. The discussion of the biologic and hydrographic phases of the question must be left to others, and in this chapter only the testimony of the structural geology and the configuration will be discussed.

The geologic composition and arrangement of the rock sheets relative to one another record in a manner changes of level, relative depth of deposition, and position of land areas. Variations in the physical and chemical composition of strata, when traced over wide areas, enable us to judge with a degree of conjecture the location of the land from which they were derived or the extent of their basins of deposition, and to construct hypotheses of former bathymetric variations. Features of land configuration by which events of elevation, degradation, and subsidence can be traced, should present harmonious and parallel conclusions with the interpretation of the fossils and the strata. Many writers of excellence, by failing to correlate the threefold testimony of configuration, biology, and geology have been led into serious errors of deduction.

Vague indeed is knowledge of the history of tropical regions prior to the Cretaceous period. Rocks of an earlier epoch are but sparsely and imperfectly exposed, being concealed even where they probably occur by the overlay of later sediments and volcanic ejecta. We know that the Appalachian and allied regions of the United States, as far west as the 98th meridian, since Paleozoic time, have been great bulwarks of land, against the southern front of which the northern waters of the Gulf of Mexico extended in Cretaceous and Eocene time, and that these old lands prior to their degradation and burial in late Mesozoic time occupied much of the southern and eastern Coastal Plain. There are also areas of old Mesozoic land of smaller dimensions in the Cordilleran regions of northwestern Mexico and the southwestern United States. In southern Mexico, Guatemala, and possibly Cuba and Haiti, there are long east and west ridges of Paleozoic rock, which may have had some fundamental relation to the east and west trends so largely dominating in the tropical region, or possibly foreshadowing the present outlines of the Great Antilles. In northern Venezuela another stretch of Paleozoic or Archæan rocks is reported to extend from the Andes north of east to the Caribbean coast and through the island of Trinidad. Paleozoic rocks also probably occur beneath the volcanic débris of Central America in Nicaragua, Honduras, and Costa Rica. The oldest rocks of Cuba and Haiti have been doubtfully considered of Paleozoic origin. Such are the earliest foundations of the great tropical amphitheatre in which during Mesozoic and Cenozoic times conflicts between land and ocean have continued, and from which amidst the vicissitudes of migrating shore lines, great oscillations of level, and volcanic extrusions, the present configuration of land surfaces and ocean bottoms have been evolved. In all of these localities south of the United States the events of Paleozoic and older Mesozoic history have been obliterated by the overwhelming phenomena of Cretaceous and later time, — buried beneath the oceanic sediments or volcanic ejecta, so that the interpretable history of the region may be said to begin with Cretaceous time.

There is some evidence that during the long period between the Appalachian revolution, after the close of the Carboniferous and the beginning of the Lower Cretaceous (Wealden epoch), the Atlantic borders of the North American coast met the Atlantic Ocean far eastward of the present continental outline, and that this expansion of the land was at its maximum during the Jurassic period.[1] No marine formations of Atlantic origin representing the intervening periods of time between the Permian and Wealden Cretaceous have anywhere been found east of the Rocky Mountain front in the North American complex, south of the Black Hills, where boreal Jurassic forms are found, which probably came from the northwest.[2] From similar data it is also evident that the northern part of the South American continent likewise had eastward expansion in Jurassic time.

The distribution of fossiliferous marine Jurassic formations on the Pacific slope of North America also shows that the border of the Pacific Ocean at that time extended far eastward of its present position. It is probable that the continental mass as a whole, practically equivalent in area to the present one, occupied a position slightly east of its present locus. In my opinion, the submerged bench of the Atlantic coast of the United States represents approximately the eastern expansion of the North American Jurassic land. How and in what manner this theoretical eastern expansion of the Western Hemisphere affected the Antillean and Caribbean regions is a question of great importance, which can be only hypothetically answered.

That the waters of the two oceans were completely separated along the American Mediterranean region in Jurassic time by a narrow land area connecting North and South America is indicated by the entire dissimilarity of the Pacific and Atlantic faunas in the oldest Cretaceous sediments, as has been often shown. Furthermore, the Pacific faunas transgressed eastward in late Jurassic time far across the present site of the Mexican Plateau, having been found in the longitude of Cuba. This indicates that the continental bridge was then far east of its present location. If the Jurassic fossils in Western Cuba, as reported by Lea, should upon further study prove to be of a Pacific type, the Jurassic Isthmus must have been situated east of the longitude of Havana.

Another line of evidence indicates that the present isthmian region presented no barrier between the oceanic waters prior to late Cretaceous time, and that if a continental bridge then existed it must have been located towards the Windward side of the American Mediterranean. This is the testimony of the deep sea fauna of the Caribbean Sea. According to A. Agassiz,[1] this is mostly of a Pacific type, which has existed in the Gulf and Caribbean since at least as far back as Cretaceous time. The minority of Atlantic forms from this fauna may also suggest that a partial barrier at least then existed to the eastward side of the Caribbean. From Florida to the northeast corner of South America we now have a chain of submerged banks, which constitute the rim of the Gulf and Caribbean basins and which may or may not represent elements of this ancient Jura-Cretaceous Isthmus, — the same which has been frequently used as data for constructing a hypothetical and impossible Windward bridge during later epochs. This is still covered by coatings of oceanic débris, or capped by volcanic ejecta, which rise at intervals as tips of land above it. The configuration of these submerged rims and islands is that of an old dissected land.

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[1] If the Wealden epoch is the top of the Jurassic instead of the base of the Cretaceous, as asserted by Marsh, it does not materially alter this proposition. The greater time of the preceding Jurassic is unrepresented so far as known by fossils or sediments on the Atlantic side of the continent.

[2] The Jurassic rocks of Mexico and Trans-Pecos, Texas, all occur, so far as known, to the westward of the east front ranges of the Cordilleras.

The submerged bench off the Floridian coast deflects southeastward towards and practically continuous with that of the Bahaman banks, where its continuity is broken by great western indentations extending along the north side of Eastern Cuba, Haiti, Porto Rico, and the Virgin Islands. Thence along the Windward Archipelago to the South American coast there are many banks which might be construed as such elements. The present outer rim of the American Mediterranean may indicate the former continuity of the Isthmian region of Jurassic time. If the Windward bridge did not exist at this period, it never existed, — certainly not since Eocene time, as will be shown later.

Hovey has described a series of specimens obtained from a well bored to a depth of 2,000 feet at Key West.[2] The Vicksburg formation was penetrated completely, the boring passing into the underlying Eocene between the depths of 1,450 and 1,875 feet. It is quite probable that the former is the base of the Vicksburg. There is indisputable geologic evidence in the land-derived material of the Eocene sedimentary rocks of the Antilles, the Virgin Islands, the Caribbees, and Barbados, that land areas from which they were derived existed in this general region in Cretaceous time.

Westward of this hypothetical bridge there could have stood but one or possibly two islets in the present Central American region south of the southern end of the Mexican Cordilleras. Rising east and west through the States of Oaxaca, Chiapas, and Guatemala, and probably in Cuba and Haiti, there are ancient ridges of Paleozoic sediments and igneous rocks, — short crescents curving to the northward and now almost lost to sight by the overshadowing pre-eminence of the grander and later topographic features that surround them. These may then have been either islands in the Jurassic sea, the nucleal lands of modern Central America, the fundamental structure of which seems to have been since developed on lines parallel to these shadowy ancestors, or the southern margin of the North American continent itself. It is possible that during the Jurassic epoch the Caribbean Sea, into which the waters of the Pacific flowed freely from the west, was partially enclosed by an archipelago consisting of a Windward bridge on the east, the old Paleozoic ridges of northern Guatemala, and southernmost Mexico, Cuba, and Haiti on the north, and the South American land on the south. Panamic America, together with the submerged Mosquito and allied banks extending northwest to Jamaica, are regions concerning which we can attempt no restoration of their history in Jurassic and early Cretaceous time, as they nowhere exhibit rocks of Pre-Cretaceous age. Neither is it possible to interpret the history of the Bartlett, Yucatan, and Gulf basins in those days. They may or may not have existed as at present in Jurassic and Cretaceous times. If they did, no data are at hand for prognosticating whether they were connected or disconnected bodies of water or connected with either ocean. The Caribbean, however, most probably, and possibly the Gulf of Mexico, were Pacific indentations at this time.

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[1] Three Cruises of the Blake, Vol. I. p. 167.

[2] Bull. Mus. Comp. Zoöl., 1896, Vol. XXVIII. No. 3.

It is a well known fact that the close of the Jurassic and beginning of the Cretaceous was a revolutionary period in American continental configuration. The gigantic Sierra Nevadan uplift, whose southern and eastward extents are not clear, elevated portions of the pre-existing Pacific borders of North America into land. Simultaneously with or just after this event in earliest Cretaceous time, the Atlantic side of the Cordilleran continent in the Mexican region underwent profound subsidence. The Gulf of Mexico was then as now an embayment of the Atlantic Ocean, which began to encroach upon the pre-existing margins of the Appalachian and Cordilleran regions. The interior shore of the Gulf migrated from the eastern part of Texas to southwestern Kansas, and degraded and buried the former southward extension of Appalachian lands then existing in the Coast Plains of northeastern Texas for a distance of 400 miles, while an embayment at its northwest corner near southwestern Kansas, indicated that the arterial Missourian-like drainage at that time was far westward of the present location. The Gulf also made a western transgression across Tropical Mexico from at least the present Gulf shore line to the present Pacific coast, and left thick deposits of chalky sediments over the areas, richly studded with remains of its animal life, but so different from similar life on the Pacific side that not a single fossil is common to the sediments of the two oceans.

The composition of these Lower Cretaceous beds clearly exhibits the fact that this subsidence deepened towards the southeast. Twenty-five thousand feet of limestones in eastern Mexico near the Tropic of Cancer, as seen by McGee and the writer, testify to the fact that it there equalled more than 6,000 fathoms, or as much as some of the greatest depressions yet discovered in the oceans, and yet there is no evidence in the Cretaceous faunas that the Pacific barrer was broken.

What happened in the Windward regions during Lower Cretaceous time can be only hypothetically conceived. Such a subsidence increasing southeastward may have been at least so far reaching in its effect as to affect and submerge the hypothetical Jurassic bridge of the Windward region. If so, the Windward barrier to the eastward was crossed by Atlantic waters, which probably came in across the north side of Southern Florida, which until very recent time has been West Indian in its relations. The absence of any known Lower Cretaceous fossils in the Antillean region suggests that a large land area may have existed during this epoch, composed of south Floridian, Bahaman, Antillean, and Windward lands.

The faunas of Trinidad and the northern regions of South America show that in Lower Cretaceous time the Atlantic waters were overcoming the southern end of the Jurassic Windward bridge, if it ever existed, and that the Atlantic littoral faunas were encroaching upon the present eastern Caribbean area, which had lost or was losing its connection with the Pacific.

In Middle Cretaceous time there was a considerable movement in the northern Gulf region, causing the land to emerge and the shore line to recede from southwestern Kansas to east central Texas. We have absolute record of the extent of this movement in the known migration of the line of the Dakota littoral. Inasmuch as all of the sedimental evidences in the littoral formations of our Coastal Plain are only the marginal phenomena of oscillations which probably had their greatest amplitude to the southward, the effects of this Mid-Cretaceous movement on the tropical regions must have been great. It was one of those oscillations which, had it occurred in later geologic time, would have been of considerable importance, but its effects and extent are completely obliterated by the grander changes which preceded and followed it. It is probable that a Central American land bridge connecting the continents via the

Isthmus of Panama was fully established at this epoch, as indicated by the stratigraphy of the succeeding Upper Cretaceous epoch, during which time events assume sufficient clearness to be more clearly interpretable in the Antillean and Caribbean regions.

In Upper Cretaceous time another subsidence ensued in North America. This produced the greatest known expansion of the Gulf of Mexico. The Dakota littoral of the Cretaceous Gulf of Mexico transgressed the Great Plains region from eastern Texas northward towards the British line, almost if not quite connecting with the waters of the Pacific and nearly separating the continent into Appalachian and Cordilleran Islands, and reaching westward towards the Sierra Nevada.

The Rocky Mountain or eastern area of the North American Cordilleran region, as far west as Utah, then became a submerged oceanic region, with ridges and islets of the older formations. The deepest deposits — the Niobrara chalks — could not be interpreted to indicate greater depths in the United States than a thousand fathoms, although the thickness of the sediments would indicate a subsidence of thirteen to fifteen thousand feet (not counting the Laramie) in the Rocky Mountain region, marked by deposition of littoral sands, carbonaceous shales, and the conspicuous Niobrara chalk horizon. All these strata, except the latter, indicated the degradation of a vast pre-existing land to the westward.

The known facts of paleontology indicate that a Central American bridge existed during the latest Cretaceous epoch. There is no evidence that the life of either ocean then passed that barrier, and old rhyolitic tuffs of Cretaceous age occur in Panama. Near the highest pass of Costa Rica, 5,000 feet above the sea, in the neighborhood of San José, there are Upper Cretaceous limestones, with fossils of Antillean facies, which show that the Caribbean Sea at that time had encroached at this locality far across the present Central American barrier. Similar limestones have also been reported from Guatemala by Sapper. These facts indicate Caribbean conditions in late Cretaceous time in portions of what are now the summit regions of Central America, and that the Cretaceous land barrier, if one existed, was then situated in a region now covered by the waters of the Pacific to the south of the present Central American land.

Vulcanism was active in the Coastal Plain and Cordilleras of western Texas, northern Mexico, along the southern end of the Mexican Plateau, in San Salvador, Panama, the Andes, and the Great Antilles. All these regions but the last were continental.

In the Antilles, instead of subsidence, volcanoes added vast accumulations of extruded débris to the pre-existing land masses, or built up islands in the sea like Jamaica, around which peculiar colonies of marine life separated from that of the continental borders by great depths were segregated.

The exact loci of the old Antillean volcanic outlets are now lost, but their débris constitutes the oldest known rocks of all the Antilles and Virgin Islands, with the exception of the few doubtful Paleozoic rocks of Cuba and Haiti previously mentioned. It is a possible hypothesis that these volcanoes were on the southern margin of an older Bahaman-Antillean land.

The close of the Cretaceous and initiation of the Tertiary was marked in both the North and South American continents by great orogenic revolutions in the Andean and Rocky Mountain regions. This is known to have affected the North American Cordilleras as far south as the south end of the Mexican Plateau, and elevated the Cretaceous sediments of the preceding northwestern extension of the Gulf of Mexico to heights of 15,000 feet or more.

In North America the material thus folded was the pre-existing Atlantic (Gulf) sediments, — and the land buttress was on the Pacific side. In South America the sea sediments folded were of Pacific origin, and the land buttress was the eastern or Atlantic side of South America. Somewhere between north latitudes 10° and 25° and longitudes 75° and 100°, including the Central American and West Indian regions, the axes of these two mighty uplifts passed each other *en echelon*. What physiographic changes occurred in the Mediterranean region between the termini of the stupendous orogenic uplifts acting upon it with tortional stress cannot readily be conceived, but changes of a most revolutionary nature undoubtedly took place.

Two of the principal events of Eocene time were faulting and vulcanism. According to Felix and Lenk, great faults of at least 12,000 feet downthrow to the southward, along which the present east and west series of living Mexican volcanoes are situated, developed along the south and east of the Mexican Cordilleras, at the great "Abfall" of the Plateau. Perhaps other faults, as described by these writers, extended in a complemental direction up the east side of the Plateau. Faulting of this epoch certainly influenced the southern part of Texas.

With the great elevation of this epoch, the shore line of the Gulf of Mexico receded with comparative rapidity from the eastern Rocky Mountain region to the interior margin of the present Coastal Plain, where it was located in Eocene time.

Vulcanism, which in the preceding Cretaceous epoch was largely dominant in the Antilles, was now active around the other borders of the Caribbean. The great accumulations of volcanic débris which now cover the southern ends of the North American Cordilleras, the northern end of the Andes, Tehuantepec, the Central American Plateau, the Isthmus of Panama, and along the Colombian coast and Windward Islands, are derived from volcanoes which had their greatest activity during early Eocene time, and are now quiescent in the Tehuantepec and Panama regions.

Stupendous masses of matter were extruded from the earth's interior, and piled upon its crust. The diastrophic effect upon the geography of these changes of mass and weight from the interior to the exterior of the earth's surface must have been appreciable. I can only say, for the present, that in my opinion that may have in some manner influenced the great series of oscillations of level which succeeded the following epochs of time from early Tertiary to the present, and which will presently be described.

Contemporaneous with and succeeding this tremendous volcanic revolution, the relative areas of land and sea were being readjusted. Degradation and deposition were shifting the load preparatory to a great subsidence soon to be initiated in the Atlantic, Gulf, and Antillean regions. Immediately after, or during the Cordilleran revolution in earliest Eocene time, an epoch of excessive littoral deposition set in, marked by great deposits of land-derived sediments, consisting of shallow water alternations of non-calcareous, ferruginous, plant-bearing clay, sands, and gravel. These were deposited around the perimeters of the Gulf and Caribbean, and on the site of the Great Antilles and Barbados. Of this nature is the Great Northern Lignite formation of the Gulf States, the Culebra formation of Panama and Central America, the Parian beds of the South American north coast and islands, the Scotland beds of Barbados, and the Richmond beds of the Great Antilles, — all essentially alike in thickness (± 1,500 feet), character, and arrangement, and evidently derived from near by lands during a great erosive epoch. In North and South America this material was derived from the interior bordering regions, but it cannot be said whence came these deposits in Central America, the Isthmus, the Antilles, and Barbados, unless there were pre-existing lands, such as I have suggested, and these must have been of large area to account for the vastness of the formations. In North Central America the old Guatemalan nucleus could have supplied only a fraction of the sediment. In Panama the source of these formations must have largely been either more extended lands than now exist, — probably in the region now covered by the Pacific waters in the south, or the regions of the submerged Mosquito and Roncador banks to the north. The lay of the formations indicates that the shore line was in the direction of the Pacific rather than the Caribbean, and this one fact, together with other considerations, may lead to the conclusion that land once existed off the Pacific side of Equatorial South America, and the submerged Mosquito banks did not then exist in their present geographic outlines.

But what was the source of these land derived sediments in the Antilles? At first it might be answered that the degradation of the Cretaceous volcanoes alone might account for this material; but, although the formation contains much volcanic material, it also has in it mica schists, quartz, and other débris foreign to the composition of the Antillean Cretaceous eruptions. Besides, the wide uniformity and assortment cannot entirely be satisfied by this hypothesis. On the other hand, the study of this material, considered from any point of view, suggests the hypothesis that the present Post-Cretaceous material was deposited upon the margin of pre-existing land areas lying to the northward, of which they were a part, including the south point of Florida, the Bahama banks, all of which may have been remnants of the northern part of the hypothetical Windward Jurassic bridge or Archipelago, and that these lands during this epoch were being base levelled and subsequently completely concealed by succeeding phenomena.

The presence of this land-derived material in the fundamental Scotland beds of the oceanic island of Barbados is indeed perplexing. The oldest formations of this little island, standing solitary and alone in the Atlantic Ocean, are clearly composed of the débris of a former land, of which there is now no track or trace unless it be the deep submerged ridge extending northward from South America. We search in vain the visible structure of the adjacent Windward Islands over a hundred miles to the westward, and separated by a deep submarine trough, for a solution, but can establish no connection between them. The only hypotheses entertainable are that they were either derived from a land now submerged, which constituted the eastern bank of the Windward platform, or from a peninsula which at that time may have extended out from the northeast corner of South America. If the latter conclusion is tenable, may we not also suppose that the Aves Island bank is also a relic of this old Cretaceous Windward land?

The early Eocene base-levelling was the beginning of initiation of a subsidence which took place in the latter part of the Eocene and early

Oligocene, which was of far reaching importance in the Gulf, Caribbean, and Antillean regions, although they but slightly affected our Coastal Plain. This profound subsidence is manifested by the nature and occurrence in the present upland structure of parts of the Antilles, Barbados, and Trinidad, of oceanic deposits composed largely of Globigerinæ and Radiolarians, such as are now known to occur at oceanic depths varying from 1,200 to 3,000 fathoms.

These beds are synchronous with the so called Jackson and Vicksburg formations of our southern coast, and their equivalents in Yucatan and Costa Rica. The exact geologic age and correlation of these beds have been ascertained by paleontologic data, and the extent and differential variations of this downward movement may be indicated in the composition of the synchronous deposits in different localities.

The effect of this subsidence upon our own Gulf coast east of the Mississippi was a slight northward transgression of the Gulf, as shown by the more mixed character of the formation around the American littoral in Mississippi and Alabama. Subsidence in that direction is distinctly recorded in the change of the Tertiary sediments from the impure land-derived character of the Lignitic and Claiborne beds into the 500 feet of limestones of the Jackson and Vicksburg epochs. The littoral nature of synchronous deposits in Costa Rica also indicates a shallower condition towards the continental shore line in that direction. In Cuba, near Havana and Santa Clara, the Vicksburg limestones contain small pebbles, probably indicative of persisting inequalities of bottom, as the land was being submerged there. Elsewhere in the Antilles and Barbados, the formation is of the deep oceanic nature described.

From the geographic occurrence of these beds I am inclined to believe that they were deposited in the troughs or deeper slopes of two great basins or depressions, separated by a ridge along the present site of the Caribbee Islands. One of these basins, the Barbadian, lay in the Atlantic proper, while the other was in the heart of the Caribbean, having an elliptical outline, whose longer and deeper axis extended through the Windward passage from Mississippi to Trinidad. This depression so largely drowned the Antilles that only the higher summits of Cuba, Haiti, and Jamaica remained above sea level as small islands. This basin shallowed rapidly towards its periphery, the Coastal Plain of the United States, the old lands of Costa Rica and Yucatan. The northern and eastern periphery of this basin during this subsidence could have been only the Bahaman, Floridian, and Windward banks, which must have been largely submerged.

The most important result of this subsidence was the fact that it submerged the Isthmus of Panama, and again permitted shallow connection between the great oceans, as I have shown in my report upon that region, — a passage which was temporarily closed shortly afterwards. All the known evidence, as presented in my recent report, tends to show that this passage was shallow and ephemeral. This is the only epoch in geologic history between the Cretaceous and the present in which there is evidence of this passage having been open.

Succeeding this Tertiary subsidence was the chief of the great orogenic movements which built up the east and west folds of the Antillean mountain systems as now occurring directly across the paths of the pre-existing Andean and Rocky Mountain trends. This undoubtedly was the most important relief producing event in all Antillean history; to it much of the present configuration of the land and sea bottom is due. The whole configuration of the Antillean lands, the western Caribbean floor, the northern shore of South America, and the Central American lands were revolutionized by the development of these corrugations, accompanied by igneous action, including great laccolithic intrusions of igneous rocks.

Seebach[1] long since pointed out the now accepted conclusion that the North American Cordilleras terminate with the "Abfall" of the Mexican Plateau, and showed the distinction between it and the entirely opposite orogenic trends in Central America and the Antilles. Suess, in his masterly compilation,[2] has still further demonstrated the existence of these trends, but owing to inaccuracies of the current geologic data he grouped the phenomena somewhat differently from the manner in which I would arrange them, having connected under the name of the Cordillera of the Antilles the true Antillean trends with those of the Caribbee chain. This, in my opinion, is not an harmonic arrangement. According to the elaborated strikes later platted by Sievers,[3] the Barbadian, Grenadan, and Aves Island ridges of the Windward bridge, at least in its southern half, are more in line with his "Carribischen" ranges of the north coast islands of South America than with the Antillean chain. These uplifts, collectively, now constitute a series of many chopped up, parallel east and west ridges, which have been greatly disconnected and partially submerged by subsequent events, but of which many distinct ranges may still be identified. The most northern of these are the Segovian trends of Oaxaca, Chiapas, Guatemala, and western Cuba, presenting a curve singularly parallel with the Trans-Mississippian extension of the southern front of the Appalachians.

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[1] Epitomized by Dollfuss and Mont-Serrat.

[2] Das Antlitz der Erde, Chapter X. pp. 698–702.

[3] Petermann's Mitteilungen, Vol. XLII., 1896, Part 6.

Next to the southward comes the true axial Antillean range of Porto Rico, Haiti, and the Santiago coast of Cuba, the Sierra Maestra of Cuba, and the Misterosa bank between the Caribbean and Yucatan Seas, to the Gulf of Honduras. From the centre of this a southern limb bifurcates and extends through the southwest peninsula of Haiti towards Jamaica, the Rosalind and Mosquito banks into northern Honduras, breaking up into numerous parallel ranges in Honduras, Nicaragua, and the submerged banks.

The continuity of the main Antillean axis of Haiti is through Porto Rico, the Virgin Islands, and St. Croix, breaking directly across the lines of the Bahaman and Caribbee trends, and not curving southward, continuously with the latter, as suggested by Suess.

A third line of Antillean trends is through the axis of the Isthmus of Panama, the Goajira peninsula of Colombia, and the islands of Curaçoa and Bonaire, pointing towards distant Barbados.

The fourth and most southern line of the group, closely related to and in echelon arrangement with the last, is the "Carribischen" system of the Venezuelan coast, embracing the Sierras Costano and Del Interior of Guaira, the peninsula of Paria, and the island of Trinidad.

I have given a general outline of the present arrangement of this system. During this epoch of mountain making, in my opinion, the land areas of the American Mediterranean received their greatest expansion and attained entirely new conformation. The Antilles were raised from submerged island peaks into a large continuous and connected land, which included most of the now submerged ridges and slopes, bringing up with them to a height of 3,000 feet above the sea the deep oceanic deposits (Globigerinal and Radiolarian earths) of the previous epoch. The Caribbean Coastal Plains of Honduras, Costa Rica, Panama, Colombia, and Venezuela were elevated above the sea and intensely folded into the present east and west ridges which occur in those regions.

The effect of this mountain making epoch is clearly and unmistakably exhibited in the geologic structure of Jamaica, Haiti, Cuba,[1] Porto

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[1] The chief orogenic movements which gave to Cuba its most rugged relief took place in late Tertiary time, as is shown in two published cross sections of the island, the first of which, by the writer, is in the longitude of Havana, and the second across the east end from Guantanamo to Sagua la Grande, by Valentine Peleterro (Boletin de la Comision del Mapa Geologia de Espano, Tom. XX. pp. 89-98, Madrid, 1895).

Rico, Barbados, the Virgin Islands, and the other regions mentioned, in all of which the Eocene strata are greatly elevated and intensely folded. For data showing the disturbance of this epoch see the various published geologic sections of the other islands.

It would be beyond all reason or interpretation of the known facts to conceive that the stupendous changes of this epoch did not affect the configuration of the adjacent sea bottoms. Neither the east and west trends of the mountain ridges, nor the mountainous configuration of the Great Antilles, cease with the margins of the water. The narrow trend of the Sierra Maestra range of Cuba, for instance, is traceable eastward by a shallow submerged ridge directly across to the northwest peninsula of Haiti, and westward by the Misterosa bank, a narrow mountainous submerged ridge lying between the Bartlett Deep and north Caribbean basin, and extending for hundreds of miles from the Sierra Maestra towards Guatemala. Furthermore, the slopes of the mountains are continued far beneath the waters. The steep declivity of the Sierra Maestra, which now projects 8,000 feet above sea level, continues downward beneath the water to a depth of 18,000 feet, showing indisputably that the present mountain phenomena of the islands are but the tips of submerged bases.

It is equally probable that the combined Mosquito, Rosalind, and Pedro banks constituted an extensive land in this mountain making epoch, connecting Jamaica with the Honduras-Nicaraguan coast. The Bahaman and south Floridian banks were also probably connected with northern Cuba, the Gulf Stream meanwhile flowing out across the northern part of Florida.

This east and west folding may have been instrumental in producing the wonderful Bartlett trough and its related depths adjacent to Cuba and Haiti, which constitute a narrow submerged furrow almost completely across the whole Mediterranean, as well as a parallel elongated submerged trough of the northwestern Caribbean lying south of the western end of Cuba and north of the Mosquito bank. These phenomena may have been initiated at a more remote epoch, but the known effects of the orogenic movements of this epoch, as now visible in the mountains of the Great Antilles, were amply sufficient to produce them.

This important Mid-Tertiary epoch of mountain making in America has not been fully appreciated, but its existence shows conclusively that in this country, as in the Pyrenees of Europe, there was a great east and west trending system at right angles to the trends of the main continental Cordilleras.

This orogenic elevation most probably united the Antillean lands, constructing bridges for the wide distribution of the ancestral forms of the wonderful land shell faunas of the Antilles from Central America to Guadeloupe, which are first found fossil in the succeeding Bowden formation. It also brought the submerged bottoms up to a height sufficient for the habitation of littoral Mollusca, and permitted them to migrate for the first time from the continental margins to the islands, and to attain wide West Indian distribution. The preceding marine faunas of Jamaica, at least of the Antilles, had been all insular and unlike that of the continental margins.

There are no geologic data to prove or disprove connection between the expanded mountainous Antillean lands with the main continent other than that a marine passage between the Gulf and the Atlantic continued across northern Florida. The absence in the Antilles of remains of continental vertebrates of this period, or living descendants thereof, would indicate that no such connection existed. Furthermore, the distribution of the land shells show that the Equatorial current was flowing into the Caribbean through breaks in the windward rims.

During this epoch the Caribbee volcanoes, persisting from the previous Eocene epoch, were in superb activity and undergoing their maximum development along the western border of the eastern limb of the submerged plateau which may have been the remnant of the probable bridge or Archipelago of Jurassic time.

The history of the western Gulf region during this epoch of Antillean uplift is obscure. Hilgard [1] has noted the absence, west of the Mississippi, of Tertiary deposits of later age than the Vicksburg, and concluded that the Gulf must have been closed on the eastern side. The probable absence from the surface west of Red River of marine deposits of late Oligocene and Miocene age,[2] and the presence of apparently fresh water formations in their place along the Texas coast, may seem favorable to this conclusion, but further study is much needed.

The evidence supporting a contrary hypothesis is of a few alleged old Miocene Gasteropods from a depth of some 3,000 feet, in the borings of a well at Galveston, which Harris alleges have Pacific affinities. No outcropping strata have as yet been discovered to support this purely paleontologic hypothesis.

However deficient may be our knowledge of the extent and details of the lands produced by this Mid-Tertiary revolution, it was certainly one of the most marked and important events in Antillean history, and produced the major configuration of the islands and adjacent waters, which have persisted notwithstanding the modifications of later times. It is true that this configuration has suffered considerable alteration in subsequent epochs, through degradation and oscillations of level, but it has remained as a major mass out of, upon, and around which all later events have been carved.

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[1] Geological History of the Gulf of Mexico, pp. 6, 7.

[2] The late Tertiary and Pleistocene history of the Texas Coastal Plain has not as yet been fully studied or interpreted.

The next events in Antillean and Central American history were the degradation, partial subsidence of the West Indian region, and dismemberment of this extended Mid-Tertiary Antillean land. The previously connected Antillean lands were severed and dismembered into almost their present outlines. The connections between the Antillean islands and the Bahaman and south Floridian lands were submerged; the waters of the Gulf Stream now flowed over the latter. The Misterosa and Rosalind peninsulas were submerged, and the littoral of the Caribbean migrated southward and westward and impinged upon what are now the land margins of Nicaragua, Costa Rica, Panama, Colombia, and Venezuela. During this epoch it is also probable that Trinidad, Tobago, and the adjacent islands were severed from the South American coast, and the disconnection of Barbados from the South American continent still further accentuated. No record has as yet been discovered showing that the Windward Archipelago participated in this downward movement. On the contrary, the formations recording it were not deposited in Barbados, and the volcanic piles of the Caribbean were more extended than at present.

The Andean, Central American, Mexican, and Windward volcanoes were as active as ever, piling up the vast eminences which from their superior magnitude have so obliterated the no less interesting minor topographic features. In this epoch ended, long before man had appeared upon the earth, all traces of Antillean land expansions upon which the least theory of an Atlantis could have been postulated, and all attempts at restoring connections between the islands, or the islands and the mainland, in subsequent epochs of late Tertiary and Pleistocene time belong to the realms of fancy.

The exact date of this late Tertiary dismemberment of the expanded Antillean lands cannot be stated with exactness. In my opinion, it was during late Miocene and Pliocene time, beginning with the Bowden epoch of the Jamaican sequence. Dr. Dall holds that the age of the Bowden beds is late Oligocene. It is my opinion that the stratigraphic relations of these beds in Jamaica indicate a later age. Deferring to Dall's opinion, I have tentatively accepted his conclusions, however, until more field work can be done.

This subsidence was the first of the group of oscillatory movements which succeeded the great Mid-Tertiary Antillean orogenic displacement, and which in succeeding cycles apparently became gradually more epeirogenic in character and successively of decreasing amplitude. While these movements in late Tertiary, Pleistocene, and recent time were far reaching and apparently of uniform character over wide fields of extent, they were rather of the nature of great swells or wide gentle folds, with movements of opposite direction in their ultimate extension, and of a nature which cannot as yet be completely harmonized with those of our Atlantic Coastal Plain. Furthermore, while in some epochs the records of these movements are most clear and unmistakable, there are others which it is exceedingly difficult to interpret, and hence their analysis as a whole is sometimes obscure.

Since the dismemberment of the Antillean lands through subsidence, the aggregate of the upward movement has not been sufficient to restore the islands to the heights they occupied during the orogenic expansion.

We have described with some care the various topographic levels which make great benches around the mountainous nucleus of Jamaica, and record phases in the physical history of the island. These levels practically belong to three great groups, the oldest of which are from 1,500 to 2,000 feet above the sea, and which may be called the Junki type; the next oldest, from 100 to 1,000, which may be called the Yumuri type; and the newest and most recent less than 100 feet. In a previous paper I have shown that these old levels are practically traceable around the island of Cuba, especially its eastern end. I can now add that they are also similarly developed on the island of Haiti. There can be but little doubt that these three series of terraces are characteristic of the Great Antilles adjacent to the Windward passage, while the two series are more widely identifiable. These stair-like terraces may record repeated intermittent upward movements, or such movements alternating with epochs of subsidence. I was unable to find in the geologic formations and structure any data to sustain the hypothesis of subsidence.

It is difficult to establish the chronology of Post-Bowden events because paleontology has given us no positive key by which we can distinguish with exactness the formations of the Pliocene, Pleistocene, and recent epochs. The calcareous Post-Tertiary material composing these islands resolves into two distinct types: coral reef rock, and white limestone and marls of shallow water origin. The limestones may be of the type of the Pliocene Manchioneal formation of eastern Jamaica, which is sparse in identifiable molluscan remains, although containing Pteropods and Brachiopods and a few thin beds of modern reef corals; or of the Falmouth type, largely composed of shells, in which the remains of a certain species of Bulla are specially abundant. I know of the occurrence of all these formations in stratigraphic juxtaposition only in Jamaica, although types of each have wide distribution throughout the Tropical region at altitudes nowhere exceeding 250 feet excepting in Barbados and the inner margin of the Caribbee Islands.

The oldest and highest group of these levels, composed of no later strata than the old Oligocene, may probably have been developed on the emerging land between the Montpelier and Bowden epochs of subsidence. They may present old levels engraved upon the margins of this Antillean land during the erosive epochs accompanying and following the culminating orogenic uplift. This is the level preserved on the summits of the Pan de Matanzas and Yunki of the north coast of Cuba, and the 2,000 foot limestone benches against the Sierra Maestra of the south side of the same island; also the John Crow and Yallahs Mountain levels of Jamaica.

The middle group may be of late Pliocene and early Pleistocene age, while the newer or coastal group, characterized by being largely composed of elevated reef rock, is the product of the late Pleistocene or recent emergence.

After the Bowden subsidence, there was further elevation, which added the Bowden formation to the Antillean margins. This was not so intense in amplitude as the preceding orogenic uplift, but far reaching in its effect and geographic importance. The Antilles were expanded to areas probably embraced by the present 100 fathom lines, enlarging the eastern and southern margins by narrow ribbons of restored land. This uplift was greatest on the continental mainland, the movement being less felt in the Antilles.

The whole of the Coastal Plain, with its Appalachian background and the Great Plains region of the United States, and probably the Cordilleran region also, participated in this upward movement. Southern Florida, heretofore West Indian in its relations, was united with the land to the north and became populated with North American mammals. The island could have had no Antillean or Bahaman connection at this time, for these mammals are not found in the latter regions. The elevation, however, was not sufficient to establish a united Antillean continent with great rivers which have since been submerged, as alleged by J. W. Spencer.[1] In the eastern and southern United States, Central America, Panama, and the Antilles, extensive degradation occurred, marked first by deep incisions of canyons on rapidly rising land and base-levelling of the borders, and next by deposition of the aggradational material over the recently formed plains. This epoch apparently corresponds with that which has been described as the Lafayette by McGee, the time of which was before the close of the Pliocene.

In the Antilles proper, and on both coasts of Costa Rica and Central America, this movement is recorded by a number of long continuous base and beach level terraces, the highest of which are 600 feet above sea level in the Antilles, as exemplified in the Yumuri terrace of eastern Cuba and about 200 feet in the Panama-Costa Rican region, as seen in the Monkey Hill and Naos benches of Panama. There are no bench marks in the Windward region by which this movement can be correlated there, the field of elevation probably not having reached so far to the eastward. If the Panama and Yumuri levels are synchronous, — and concerning their identity we are not yet fully satisfied, — there is evidence of a considerable difference in amplitude of uplift between the two points, the greatest movement having been in that portion of the Antilles adjacent to the Windward Islands, there exceeding that of the Panama coast by some 500 feet.

During this epoch vulcanism was continuously active in all the present regions of living volcanoes, as well as in the Cordilleran region of the United States, although expiring in the latter.

The margins of the present Antilles and Caribbean and Gulf mainlands were flooded by the seas in late Pliocene time, and subsidence may be presumed. The continental coastal plains of south Florida, Mexico, Yucatan, Costa Rica, and Trinidad, the lowlands of the pre-expanded Antilles, and the Atlantic margin of the Windward platform, were veneered during Pliocene time with a coating of oceanic débris composed of shells and calcareous muds. How the western Gulf region was affected during this epoch cannot be stated with clearness at present, but from the fact that the rivers of the back coast country of Texas were partially drowned and partially refilled with alluvial sediments, it is probable that that region was much lower than at present. In Tehuantepec and Costa Rica the Pliocene marine deposits indent the Gulf and Caribbean coasts for a considerable distance inland. During this epoch the Antilles were restricted to a fraction less than their present dimensions.

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[1] Reconstruction of the Antillean Continent. Bull. Geol. Soc. Amer., Vol. VI. pp. 103–140, Rochester, 1895.

This subsidence of late Pliocene or early Pleistocene time did not lower the Isthmian barriers sufficiently to permit the commingling of the two oceans across them, or to divert the Gulf Stream across it in Pleistocene time, as has been frequently asserted, nor is there a single fact in the geology or geomorphology of the Isthmus of Panama to warrant this conclusion. How long this subsidence persisted in the Tropical regions cannot be stated with accuracy.

There is one point in this history which seems to present a hiatus. There should be some record of a subsidence in early Pleistocene time corresponding with the great Columbian depression of the North American coast in the Glacial epoch. We must confess, however, that the structure of the islands affords no data whereby it can be exactly established in the islands, although the Isthmian and Texan coasts clearly record traces of such an episode.

Following this Pliocene expansion were a number of pseudo epeirogenic elevations which probably continued from Pleistocene time to the present, marked by a series of interrupted uplifts of a large portion of the West Indian region, bringing the pre-submerged plateaux, ridges, and benches to altitudes sufficiently near the surface (fifteen fathoms) to permit the growth of modern coral reefs, which as the elevation progressed were elevated above the water, while other slopes of the submerged lands were brought successively within the limits of the reef coral growth, by which they are now inhabited.

These later elevations of the West Indian region are recorded in the elevated reef and wave-cut bench and bluff topography or newer terraces of all the islands except the Leeward side of the Windward Islands. The topography, whether seen against the margins of the older mountainous islands of the Great Antilles, or in isolated islands like Barbuda, Desirade, Alta Viela, Navassa, or a dozen other examples that might be quoted, is the most striking modern feature of the West Indies, and consists of a series of two or more low benches and escarpments rising above the sea. In Jamaica, besides the higher benches of older origin, they comprise four benches, the oldest and highest of which is composed of elevated Pliocene marls, and the three lowest of elevated coral reef rock. Barbuda, Sombrero, Navassa, and others, show a double terrace, consisting of a low coastal bench surmounted by a higher mesa summit.

The newer group of terraces is traceable and recognizable throughout the islands and margins of the whole West Indies, with the exception of the Bahamas, the west side of the Caribbee volcanic chain, and perhaps the islands and coast of the north side of Venezuela, showing the wide extent of the recent epeirogenic uplifts. The elevated reefs of the West Indies, especially those forming the Great Antilles, are all manifestations of this event. On the mainland of Florida, Texas, Yucatan, and Panama, it is recorded in the elevated position of synchronous Post-Pliocene formations of diverse material above sea level. Many small isolated islets, like Barbuda, Desirade, Marie Galante, and Basse Terre of Guadeloupe, making the eastern limit of the Windward Islands, with their double benches, show their wide extent in that direction. Other isolated disconnected islets, like Navassa, southeast of Haiti and Alta Viela, show the same unmistakable record in their benched topography.

All these recently elevated benches are not reef rock, but many of them are wave-cut terraces. In Barbuda, for instance, they are composed of old beach and shallow littoral débris, now cemented into limestone, as are many of the Florida Keys described by A. Agassiz. It may be that the higher summits of the low benched islands of the Barbuda and Navassa type are remnants of the oldest Post-Pliocene elevation, and that the lower terraces record a later Pleistocene uplift.

Whether constructional benches of elevated reef rock or wave-cut cliffs and terraces, these phenomena are all manifestations of the same general uplift that has taken place in Tropical America since the Pliocene subsidence we have described.

The known data of the wide area of these Pleistocene and later uplifts, as uniform as they appear, present some interesting facts showing important differential movements. These are characterized by wide extent and small amplitude. The region of greatest uplift, excepting Barbados, is adjacent to the Windward passage, where a maximum of at least 600 feet is recorded. From this locality the amplitude decreases north, south, and west, the elevation being only a few feet at Colon and in southern Florida. To the south of east as far as Barbuda and Desirade east of Guadeloupe, the amplitude maintains an altitude of over 125 feet, indicating that the uplift was a very gentle oval swell, having an east and west axis. From Barbuda to Colon is about twenty degrees of longitude, or over 1,300 miles, and at the extremes and middle of this line there are stations by which the differentiation of the movement can be determined, and these show that considerable differences exist. At Barbuda the highest bench is 125 feet; at Navassa in the centre, 250 feet; at Colon on the west, five feet.

In the region of the Bahamas, according to A. Agassiz, subsidence has been progressing during epochs which correspond with these regional uplifts in the Antilles.

The uniformity of this epeirogenic movement is also broken at two places by synchronous orogenic deformation: on the Leeward side of the Windward Islands, where the modern reef rock is found 300 feet above the sea in disturbed patches, and at Port Limon, Costa Rica, where the Pleistocene beds are deformed. Furthermore, at the eastern extremity of the region, the island of Barbados, the Post-Pleistocene uplift is entirely discordant with that of all the rest of the region, the coral reefs of Barbados having risen to an altitude of 1,100 feet.

Synchronously with the rising of the reef, volcanic piling has continued on the mainland and in the Windward Islands, although the mass of ejecta during these later days is Lilliputian in comparison with the great heaps of débris piled up in preceding epochs. The present craters and vents of the Mexican, Costa Rican, and Windward summits are mere anthills capping the older mountains of ejecta. The last volcanic fires of the Cordilleran region of northern Mexico and the United States expired in Pleistocene time.

The differing altitudes of the synchronous elevated reefs teach some important lessons. On close analysis they show that the apparent uniformity of uplift does not persist, and resolves itself into a wide, swell-like movement, with different intensities in various parts of the field, gradually decreasing towards the United States, where hitherto Post-Pleistocene movements of the West Indies and the continent had been considered so uniformly continuous. These inequalities in the Post-Pleistocene uplifts of the West Indies also controvert the position maintained that the elevated terraces might be due to shrinkage of the sea rather than elevation of its bottom.

The data presented are insufficient to show enough expansion of the West Indian lands in Post-Oligocene times to have connected the islands with the mainland or with one another, or to have created a continuous Windward bridge, as has been alleged.

RÉSUMÉ.

With the data presented, we can now briefly review the major processes of diastrophism which have produced these great changes of level in the Tropical region in later Mesozoic and Cenozoic times, and their effects upon the configuration of the lands.

It is apparent that the borders of the region were indicated after the Appalachian revolution, at which time protean lands existed to the north and south in the then separate Americas. It is even possible that corrugations of Pre-Mesozoic rocks now concealed may have at that time underlain the North American Coastal Plain, and established the fundamental trends of the Floridian, Mexican, Central American, and Windward ridges, especially the long east and west Segovian ridge or ridges of Guatemala, and its possible extension into Cuba and Haiti, which constitute the most northern of the Tropical ranges.

The Sierra Nevadan revolution, at the close of the Jurassic time, undoubtedly played an important part in establishing the northwestern barrier of the Mediterranean region, and creating a permanent nucleus for the accumulation of subsequent lands against it. The present abrupt termination of the trend of the Sierra in southern California, and the absence of trends directly continuous therewith in northern Mexico, does not necessarily imply that related uplifts may not have occurred in the western Sierra Madre region of that republic concerning which we now know so little, except that its diminishing summits towards the American border, formulated by the later movements, are trending towards the Colorado Plateau. There may be nucleal lines of the older Nevadan trend in the Mexican region parallel to and *en echelon* with the Californian Sierra. No trace of this revolution can even be hypothecated elsewhere to the southward in the Tropical American region.

The Andean and Laramide (or Rocky Mountain) revolutions of late Cretaceous and Eocene time, although synchronous in age, have not thus far revealed continuity across the Tropical zone. As has been shown, no possible protraction of their trends can be connected across it. Neither can their trends anywhere be identified in Central America or the West Indies, where, on the other hand, the orogenic trends are directly across their paths and at right angles to them. The only visible effect of the Laramide movement upon Tropical America was to add another belt of land, the Mexican Plateau, to the previously existing continental mass northwest of the region.

The Antillean uplifts which occur in the West Indian region (Great Antilles and Virgin Islands), Central America, and the Isthmus of Panama and the ranges of the Colombian-Venezuelan coasts and islands, constitute the members of the latest and most important mountain movement, and one which produced the present configuration of the region mentioned.

On closer study this system presents several interesting minor trends, and its history reveals a complexity of movements. In Jamaica, for instance, and those islands around the Windward passage in the very heart of the region, two movements of different epochs and axial directions can be traced. The oldest of these produced the intense folds of higher summits of eastern Cuba, Jamaica, and western Haiti, composed of terrigenous and volcanic débris of Eocene and Cretaceous age. A subsequent subsidence destroyed the pre-existing continuity, and coated the lower slopes of these mountains with 3,000 feet of purely oceanic deposits. This was followed by another uplift of Mid-Tertiary time, which was produced or accompanied by the vast igneous intrusions. The trends produced by these two events are quite distinct. Those of the older uplift are northwest and southeast in Jamaica and Haiti, and continued with the Sierra Maestra of Cuba, and constitute an almost closed amphiteatre of summits, broken only in the west by the Bartlett Deep.

The trends of the later Miocene uplift, which added the present white limestone areas to the Antilles, are strictly east and west, and the structure is that of simple open anticlinal folds.

In the Panama and Honduras trends active vulcanism was in operation during the earliest of these mountain making epochs, the chief erupted material being augite-porphyrites. The second orogenic epoch in the Antilles was accompanied in the Panamic, Costa Rican, and Carribischen ranges by intrusions of a different nature.

The foregoing facts all lead to the conclusion that the orogenic growth of the cross ranges of the Tropical region was a series of intermittent processes. These were probably initiated back or before the early Mesozoic, as shown by the uplifts of the Segovian ranges which are concentric with the southern margin of the older Appalachian trends. This may have been followed by movements in the later Mesozoic not yet deciphered. The chief revolutionary movement effective in producing the present configuration occurred in the Miocene Tertiary. The Post-Eocene age of these uplifts is undoubtedly attested by the fact that in all the regions mentioned, including the Segovian, where older rocks also occur, the ranges are composed of intensely folded Eocene and Oligocene strata which have been cut through by granitoid and basic intrusives.

Concerning the origin and succession of volcanic events, the following facts can be stated. In late Cretaceous time vulcanism was active in the now quiescent regions of the North Mexican and Trans-Pecos Cordilleras, the Coastal Plain of Texas, the Isthmus of Panama, and the Great Antilles, Jamaica then being a volcanic island. The late Cretaceous limestones of Costa Rica contain angular specks of volcanic material intermixed with them, as also do the late Eocene sediments of Panama, which facts lead us to believe that the present Central American volcanic plateau has been an intermittent locus of volcanic activity from the Cretaceous to the present, as also has the volcanic region of Mexico.

The volcanoes of the Windward Islands, in my opinion, date back to at least the Eocene. In Mid-Tertiary time granitoid intrusions were pushed upward into the sediments of the Great Antilles, the Carribischen, Costa Rican, and Panamic regions. How extensively this remarkable event affected the Andean and Cordilleran regions we cannot say, except that we have fragmental data which lead us to conclude that it certainly extended to the Mexican Plateau, while Cross reports that the rocks of this epoch from Jamaica are singularly like the material of certain laccoliths of Mid-Tertiary age in Colorado.

After the Miocene vulcanism became quiescent in the Great Antilles, and the Coastal Plain of Texas, but has continued to the present in the four great loci of present activity, — Southern Mexico, the Northern Andes, Central America, and the Windward Islands. In the last two regions mentioned, the greater masses of the present volcanic heights were piled up before the Pliocene, and the present craters are merely secondary and expiring phenomena.

The wide occurrence of benches and terrace levels in the Tropical region is as conspicuous and important a topographic feature as the folded and volcanic mountains. Whether made by degradational or constructive processes, they record with unusual clearness the later regional movements, and in a manner corroborate the history recorded by sedimentary and paleontologic evidence. The three distinct groups of these phenomena of late Tertiary, Post-Pliocene, and Post-Pleistocene epochs respectively, having their typical development in the Antilles, around the Windward passage, are traceable, with local modifications on both sides of the Costa Rican divide. In the Windward Islands only those of the two later groups are positively defined as yet, while in Barbados only those of the last epoch occur under entirely anomalous conditions.

With the date presented we can summarize the known history of the Antillean region as follows: —

1. The geology and configuration present no evidence whatsoever whereby past land connections can be established between these islands and the North and South American lands in Post-Jurassic time, especially in the Tertiary, Pleistocene, or recent epochs.

2. The configuration and conditions of these islands in Pre-Jurassic time cannot even be surmised.

3. There are some hypothetical and biologic reasons for believing that the outer rim of the American Mediterranean constituted a partial or complete bridge between the continents in Jurassic time, and that the Panama bridge did not then exist.

4. The first definite evidence of Antillean lands is found in the eruptive rocks of late Cretaceous time, when it is probable that there were marine volcanoes.

5. The land débris constituting the Eocene strata throughout the islands testifies the pre-existence of extensive Cretaceous land areas.

6. There was a profound regional subsidence in late Eocene and early Oligocene time, which submerged all but the highest tips of the Antilles, and which extended to the margins of the surrounding continents.

7. In late Oligocene or Miocene time there was a tremendous orogenic movement which resulted in uplift, whereby many of the islands were connected with each other, and possibly an insular southern portion of Florida, but not establishing land connection with the North and South American continents.

8. In Miocene or early Pliocene time the islands were severed by submergence into their present outlines and membership, which they have since retained with only secondary modification.

9. In Pliocene and Pleistocene time there have been intermittent periods of elevation without serious deformation, but not sufficient to establish land connections or to restore the islands to the heights and areas of Mid-Tertiary time. The Pleistocene movements, while epeirogenic, were sufficiently differential to show that they were not uniform in all parts of the area, showing great differences in amplitude within the West Indian area, and were not harmonious with those of the North American coastal plain.

10. The irregularities of the submerged configuration of the West Indian region are orogenic, and not due to submerged continental drainage systems.

11. The elevated coral reefs of the West Indies were formed on rising lands.

PART VII.

APPENDICES.

I.

ADDITIONAL NOTE ON THE GEOLOGY OF PORTO RICO AND SANTIAGO DE CUBA.

SINCE the foregoing pages were placed in type I have made a geological reconnoissance of Porto Rico and Santiago de Cuba. In the former island I found the general Antillean sequence, but modified by certain features hitherto known only in the Caribbean chain: — 1. An older plexus of water-sorted hornblendic volcanic material, — tuffs and conglomerates with interbedded Cretaceous Rudistean limestone similar to that of Jamaica, composing the central mountains. 2. An Eocene system of impure lignitic sands and clays like the Richmond beds, occurring on the western side of the island near San Sebastian. 3. Fossiliferous marl beds overlapping the above, which at this writing have not been determined. 4. Miocene coral limestone, unlike anything hitherto recorded from the Great Antilles, but of the type occurring in Antigua. These constitute the hilly country north and northwest of Lares. 5. White limestones of probable Pliocene age, composing the hills of the south coast. 6. Elevated reefs, but feebly represented. 7. Alluvial plains of Pleistocene age. The terrace phenomena are less developed upon this island than in any of the other Great Antilles, although the Pleistocene base-levelling is well developed in stream valley phenomena. Dikes of syenitic-like porphyry, probably diorites, were also noted cutting the older hornblendic rocks.

Evidence was obtained indicating that the greater mountain movement culminated before the Miocene, and that there has been at least one thousand feet of vertical uplift since that epoch.

My researches at Santiago de Cuba, consisting of a section across the Sierra Maestra from the coast to the Rio Cauto, convinced me that the crystalline rocks of that region are Cretaceous and Post-Eocene Tertiary, and not Paleozoic, as asserted by Frazer; and I am more than ever inclined to doubt his conclusions and those of Bergt relative to Cuba and San Domingo. The descriptions of the region by Kimball are approximately correct and reliable.

II.

SOME CRETACEOUS AND EOCENE CORALS FROM JAMAICA. BY T. WAYLAND VAUGHAN.

Introductory.

Mr. Robert T. Hill has submitted to me for study the various fossil corals that he has collected in his visits, made for Professor Alexander Agassiz, to the West Indian Islands. The following paper has grown out of a study of a part of this material, i. e. the so called Cretaceous and the Eocene species.

Duncan is the only author who has contributed to the paleontologic literature on corals of these ages from Jamaica. His first paper, published jointly with Wall, "A Notice of the Geology of Jamaica, especially with reference to the District of Clarendon; with Descriptions of the Cretaceous, Eocene, and Miocene Corals of the Island,"[1] contains notices or descriptions of the following "Cretaceous" and Eocene species: —

Lower Cretaceous.

Diploria crassolamellosa, Edwards and Haime.
Heliastræa exsculpta, Reuss.
Heliastræa cyathiformis, sp. nov.
Cyathoseris haidingeri, Reuss.
Porites reussiana, sp. nov.

Five species in all, three of which are identified with European species and two described as new. As Duncan compares these species with the Gosau fauna, I took the opportunity while in Europe to visit the K. K. Naturhistorisches Hofmuseum in Vienna and study Reuss's types of the Gosau corals.[2] Later I went to London and studied in the collection of the Geological Society of London the originals and types of Duncan.[1] The result of this study was somewhat as I anticipated, — all of Duncan's identifications with European species are wrong. The *Diploria crassolamellosa* (described in this paper as *D. conferticostata*) and *Cyathoseris haidingeri* of Duncan are both new species. Later I have described the former; the latter is still undescribed. Mr. Hill has collected no specimen of it in his travels, and I did not have time while in London to study the species properly and have figures drawn. Duncan's *Heliastræa exsculpta* is not only not the same as the *Heliastræa exsculpta* of Reuss, but does not belong to the same genus. It is a synonym of *Heliastræa* (= Multicolumnastræa, gen. nov.) *cyathiformis*, Duncan. This breaks down absolutely any comparison of the Jamaican corals with those from the Gosau. It might be added that the Gosau is not Lower Cretaceous, as Duncan states, but high in the Upper Cretaceous.

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[1] Quart. Jour. Geol. Soc. London, 1865, Vol. XXI. pp. 1-15.

[2] I am deeply indebted to Prof. Theodore Fuchs, Director of the Geological Department of the Imperial Hofmuseum, and to Drs. Wähner and Kittl for giving me every facility possible in my studies. Prof. E. Suess gave me access to all the collections at the University of Vienna, and I express my hearty thanks to him.

Eocene.

Paracyathus sp.
Stylophora contorta, Leymerie sp.
Stylophora contorta, var. nov.
Stylocœnia emarciata, var. Lamarck sp.

Duncan has published no descriptions or figures of these species, and only very scanty notes. I made the following notes on the original specimens in the collection of the Geological Society of London.

Paracyathus sp., which Duncan compares with *P. caryophyllus* (Lamarck).[2] The specimen is a fragment, so poorly preserved that one cannot determine any essential characters. Locality, "Black Shales, Grass Valley, Jamaica," according to label in collection of the Geological Society; "Yallahs Valley," according to Duncan.[3]

Stylophora contorta, Leymerie sp. (Duncan). I could see no reason for separating the specimens specifically from *Stylophora affinis*[4] of Duncan. The walls between the calices are usually not so thick. As the surface ornamentation has been eroded, the specimens cannot be accurately described.

Stylocœnia emarciata, Lamarck sp. (Duncan) from Port Maria. There are thickenings at the corners of some calices, and there appear to be remains of some pillars, so the coral is pretty surely a *Stylocœnia.* The septa are apparently in two cycles of eight septa each, eight large septa, and eight small, making a total of sixteen. The walls are rather thin, .3 to .5 mm. thick. The calices are irregularly polygonal in outline, their diameters usually 2 mm. The calices are smaller than the measurements given by Edwards and Haime;[1] they give 2.5 mm. for *Stylocœnia emarciata.* The detailed characters of the pillars and of the upper surface of the wall cannot be made out. Later in the present paper I describe this as *Stylocœnia duerdeni.*

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[1] For this privilege I am indebted to Mr. William Rupert Jones, Librarian, and Mr. L. L. Belinfante, Secretary of the Geological Society. Mr. C. Davies Sherborn, who was cataloguing and labelling the types in the Society's collections, did everything possible for me.

[2] *Op. cit.*, p. 8.

[3] *Op. cit.*, pp. 9, 13.

[4] Quart. Jour. Geol. Soc. London, 1863, Vol. XIX. p. 436, Pl. XVI. Fig. 4.

In a later paper,[2] Duncan describes another species, *Columnastræa eyeri*, sp. nov., from "Eocene shales, Jamaica." As he published a fair description and figures of this species, no further remarks are needed. In this same paper, in the table of West Indian fossil corals,[3] *Paracyathus crassus*, Edwards and Haime, is cited from "Jamaica, Eocene." The original specimen is indeterminable, and needs no consideration.

Duncan's last contribution to West Indian paleontology is "On the Older Tertiary Formations of the West Indian Islands."[4] This paper deals with a collection of corals, made by Mr. P. T. Cleve on the island of St. Bartholomew, and considered by Duncan as of Eocene age. Duncan lists or describes the following species:—

Flabellum appendiculatum, Brongniart sp.
Stylophora compressa, sp. nov.
S. distans, Leymerie sp.
S. conferta, Reuss.
S. tuberosa, Reuss.
Trochosmilia subcurvata, Reuss (figured).
T. subcurvata, var. nov.
T. insignis, sp. nov.
T. arguta, Reuss (figured).
Asterosmilia pourtalesi, sp. nov.
Stylocœnia emarciata, Lamarck.
Stephanocœnia incrustans sp. nov.
S. elegans, Leymerie sp.
Astrocœnia multigranosa, Reuss.
A. ramosa, Sowerby sp. var. 1 and 2.
A. d'achiardii, sp. nov.
Ulophyllia macrogyra, Reuss.
Plocophyllia caliculata, Catullo sp.
Manicina areolata, Linn. sp.
Leptoria profunda, sp. nov.
Circophyllia compressa, sp. nov.
C. clevei, sp. nov.
Goniastræa variabilis, sp. nov.
Solenastræa columnaris, Reuss.
Turbinoseris eocænica, sp. nov.
T. major, sp. nov.
T. grandis, sp. nov.
T. angulata, sp. nov.

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[1] Hist. Nat. des. Corall., Tom. II. pp. 251, 252.
[2] Quart. Jour. Geol. Soc. London, 1868, Vol. XXIV. pp. 17, 18, Pl. I. Figs. *1a*, *1b*
[3] *Op. cit.*, p. 23.
[4] Quart. Jour. Geol. Soc. London, 1873, Vol. XXIX. pp. 548–565.

Turbinoseris antillarum, sp. nov.
T. clevei, sp. nov.
T. cyclolites, sp. nov.
Astræopora panicea, Pictet.
Actinacis rollei, Reuss.
Porites ramosa, Catullo.

The originals and types of these species are partly in Stockholm and partly in the collection of the University of Upsala. I have not been able to make the journey necessary for seeing them. I am confident that the collection needs very careful revision, after having studied, with Duncan's work in hand, the types of all of the species of Reuss with which he identified West Indian species. I have studied also specimens of all the other European species considered by Duncan in his paper. The corals from St. Bartholomew have an undoubted Eocene or Oligocene facies.

Résumé of the Hill and Jamaica Institute Collections by Localities.

Solomon Mountain, west of Mint, Westmoreland Parish: Cladocora jamaicaensis, sp. nov.; Leptophyllia agassizi, sp. nov.

Craigie, Parish of Hanover: Stiboriopsis jamaicaensis, gen. et sp. nov.

Pennants, District of Clarendon, Parish of Clarendon: Diploria conferticostata, sp. nov.

Mount Hindmost, District of Clarendon, Parish of Clarendon: Multicolumnastræa cyathiformis (Duncan).

Point Haldane, Port Maria, District of St. Mary, Parish of St. Mary: Stylocœnia duerdeni, sp. nov.

Catadupa: Trochosmilia hilli, sp. nov.; Multicolumnastræa cyathiformis (Duncan); Diploria conferticostata, sp. nov.; Diploria conferticostata, var. columnaris, var. nov.; Trochoseris catadupensis, sp. nov.; Mesomorpha catadupensis, sp. nov.

Near Cambridge Station, south of Montpelier, St. James Parish: Turbinoseris jamaicaensis, sp. nov.; T. cantabrigiensis, sp. nov.; Dendracis cantabrigiensis, sp. nov.

The Faunal Relations of the Jamaican Pre-Bowden Corals.

Because of insufficient description or the undeterminable character of the original specimens of Duncan we must eliminate Cyathoseris haidingeri, Duncan (non Reuss); Paracyathus sp., cf. caryophyllus, Lamarck; Paracyathus crassus, Edwards and Haime.

Arranging the other species according to Hill's stratigraphic succession, we have:—

Cretaceous.

Blue Mountain Series. Cladocora jamaicaensis, sp. nov.; Leptophyllia agassizi, sp. nov.; Solomon Mountain. Stiboriopsis jamaicaensis, sp. nov., Craigie, Parish of Hanover. Multicolumnastræa cyathiformis (Duncan), Mount Hindmost, Trout Hall, and Cupius. Diploria conferticostata, sp. nov.; Trout Hall and Upper Clarendon District, Pennants in Upper Clarendon District. Porites reussiana, Duncan, Upper Clarendon District.

Eocene.

Richmond Beds. Stylophora contorta, Leymerie sp. (fide Duncan), Port Maria. Astrocœnia duerdeni, sp. nov., Port Maria and Point Haldane, St. Mary Parish. ? Columnastræa eyeri, Duncan, Locality ?

Cambridge Beds: Turbinoseris jamaicaensis, sp. nov.; Turbinoseris cantabrigiensis, sp. nov.; Dendracis cantabrigiensis, sp. nov.; near Cambridge Station.

Catadupa Beds. Trochosmilia hilli, sp. nov.; Multicolumnastræa cyathiformis (Duncan); Diploria conferticostata, sp. nov.; Diploria conferticostata, var. columnaris, var. nov.; Trochoseris catadupensis, sp. nov.; Mesomorpha catadupensis, sp. nov.; Catadupa.

We appear to have in these corals the unusual condition of several Cretaceous species ranging far up into the Eocene. Mr. Hill has a lengthy discussion of this subject in his report on Jamaica.

There are six species from the Blue Mountain Series. As two of them belong to new genera, any evidence for geologic age must be drawn from the remaining four. The genus *Cladocora* ranges from Jurassic to present time, so the first species is indefinite in its evidence. *Leptophyllia* is Jurassic, Cretaceous, and Eocene, but the Jamaican species, *L. agassizi*, seems more closely related to the Cretaceous forms. The range of *Diploria* is from Cretaceous to the present. The nearest species to *D. conferticostata* is an Italian Eocene species. The genus *Porites* is a Tertiary genus, and if Duncan's generic diagnosis is correct, the *Porites reussiana* would argue for the age of the beds in the Upper Clarendon District being at least not older than Eocene. If the genus of the species should be *Litharæa*, as I suspect to be the case, it might be Cretaceous, but it seems more closely related to some of the Eocene species. It seems to me that there are two faunas in the Blue Mountain

Series, one from Solomon Mountain and most probably Cretaceous; the other from the Clarendon District, practically identical with the Catadupa fauna, might be Eocene in age.

The Richmond beds are undoubtedly Tertiary, and from the similarity between *Stylocœnia duerdeni* and *Stylocœnia emarciata*, I believe Duncan was correct in referring the beds whence they were derived to the Eocene.

The Cambridge beds can be referred to the Eocene (or possibly Oligocene) on the strength of their containing abundant specimens of *Dendracis*. This genus is not known from rocks older than Eocene or younger than Oligocene. Both specimens and species are abundant in Southern Europe and Northern Africa in strata of these ages.

The Catadupa beds also can probably be referred to the Eocene on the evidence of the *Trochosmilia*, which has a near European relation in *T. acutimargo*, Reuss. The *Diploria* also has a European relation. *Trochoseris* is a doubtfully Cretaceous genus; it occurs in the Eocene, and there is a recent species. The occurrence of the species of *Diploria* and *Multicolumnastræa* in the Blue Mountain Series has been noted.

The faunas from the Richmond, Cambridge, and Catadupa beds seem quite different from the St. Bartholomew fauna, described by Duncan. Apparently they possess only one species in common, viz. the *Stylocœnia*, identified by Duncan as *emarciata*. The stratigraphic affinities of the Jamaican species for European species are the same as those of the St. Bartholomew corals, and I believe more extensive study and collecting will show considerable resemblance, — especially after a revision of Duncan's types from St. Bartholomew.

A very interesting fact is the great difference between the Eocene corals of Jamaica and those from the United States. I am very familiar with the Eocene corals from the latter, having just prepared an extensive monograph on them. So far not a single species common to both has been found. Eocene corals are very abundant in the United States, but they are mostly simple species belonging in large part to the genera *Flabellum*, *Turbinolia*, *Sphenotrochus*, *Caryophyllia*, *Trochocyathus*, *Paracyathus*, *Discotrochus*, *Platytrochus*, *Parasmilia*, *Eupsammia*, *Balanophyllia*, *Endopachys*, and *Stephanophyllia*. *Oculina*, *Madracis*, and *Dendrophyllia* are well represented. In the Oligocene deposits of Mississippi, Alabama, and Florida, there are many compound forms. A species of *Mesomorpha* occurs in the Lower Eocene (Midway beds) of Alabama.

DESCRIPTION OF SPECIES.

TROCHOSMILIA, Edwards and Haime.

Trochosmilia hilli, sp. nov.

Plate XXXVI. Figs. 1-4.

Form irregularly cyathiform, with a stout thick pedicel about one half the length of the corallum. Height of corallum about 22 mm. The calice oval, with a slightly sinuous outline. Greater diameter 23.5 mm.; diameter at right angles to the greater, in the plane containing the vertical axis, 15.5 mm. The costæ are very fine, alternating in size, with beaded margins, as shown in Figure 3, Plate XXXVI. The crowded, very fine, beaded costæ appear to be splendid specific characters. Septa very numerous, thin and crowded. One hundred and ninety septa were counted in the type. The systems and cycles, probably due to the irregular transverse outline of the calice, are not distinctly differentiated, but there appear to be six complete cycles. The total number of septa for a calice with six cycles is 192. The septal margins are not dentate, but there are striations extending across them perpendicular to the flat planes of the septa. The calicular fossa is rather shallow, the calice being wide open, with a small depression in the centre. No columella; the edges of the principal septa meet in the axial space.

Locality. Catadupa, Jamaica (collected by R. T. Hill).

Type. Museum of Comparative Zoölogy.

Remarks. This species bears considerable resemblance to the *Trochosmilia acutimargo* of Reuss, from the Eocene of Monte Grumi, near Castel Gomberto, and Monte Carlotta,[1] Northern Italy. I would call especial attention to the specimen figured in Vol. XXVII. of the Denkschriften of the Vienna Academy of Sciences.[2]

I had the opportunity to study the original figured specimen of this form in the University of Vienna geological collections. The chief difference between the two species seems to consist in the difference in the character of the costæ. The costæ of *acutimargo* are acute or moderately rounded, while in *hilli* the sides of the costæ are perpendicular to the wall of the corallum.

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[1] Denkschrift d. Wiener Akad. d. Wissenschaft Mat. Naturhist. Cl., 1868, Bd. XXVIII, Plate I. Fig. 1. Denkschrift d. Wiener Akad. d. Wissenschaft Mat. Naturhist. Cl., 1874, Bd. XXXIII., pp. 26, 27, Plate XLIII. Figs. 3–7.

[2] In this volume, page 189, Reuss calls this species *Trochosmilia profunda*, but later, in Vol. XXXIII. of the same series of publications, he shows that he had at first confused two species under the name *profunda*, and separates the forms into *T. profunda* and *T. acutimargo*, Plate I. Fig. 1, Vol. XXVIII., taking the latter designation.

By comparing the description given above of *hilli*, with Reuss's excellent description of *acutimargo*,[1] the close relationship of the two species will be very apparent.

CLADOCORA, Ehrenberg.

Cladocora jamaicaensis, sp. nov.

Plate XXXVI. Figs. 5-7.

One specimen has been submitted to me. It consists of many branches of *Cladocora* firmly embedded in an indurated matrix of dark colored calcareous sand and clay, or argillaceous limestone. In places the matrix is stained yellow by oxide of iron.

The greatest length of the branches could not be made out, but one piece measured at least 65 mm., and another 50 mm. The following will show the size, in millimeters, of the corallites in cross section. The numbers marked by asterisks are young.

	1	2	3	4	5*	6*
Greater diameter . .	7.5	6.5	8	7	5	4
Lesser " . .	6.	5.	6.5	5	4	3.5

The distance apart of the branches in the colony is variable, but they are not much crowded, the usual distance being from 3.5 to 7 mm. To be sure, in some instances the branches may be closer together or farther apart. No epitheca was observed. The outside of the corallites is marked by low acute costæ, corresponding to all septa. In size they may vary according to the cycles of septa to which they respectively belong, or may be subequal. The septa are in four complete cycles, and there may occasionally be some members of the fifth. The larger septa show thickenings on their inner ends, probably pali. There are not many dissepiments, those present are thin and belly inward toward the centre of the corallite. The columella is variable in its development: in one young calice there is no columella, the axial space being vacant; in other corallites there are a few processes from the septal ends forming a very insignificant false columella, while in others the septal processes have formed a distinct well developed false columella. Reproduction by lateral gemmation, two buds may stand opposite each other, as in Figure 6, Plate XXXVI.

Locality. Solomon Mountain, west of Mint, Westmoreland Parish (R. T. Hill, collector).

Type. Collection of Museum of Comparative Zoölogy.

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[1] *Op. cit.*, Vol. XXXIII. pp. 26, 27.

STYLOCŒNIA, EDWARDS AND HAIME.

Stylocœnia duerdeni, sp. nov.

Plate XXXVII. Figs. 1-4.

1865. *Stylocœnia emarciata*, Duncan (non Lamarck), Quart. Jour. Geol. Soc. London, Vol. XXI. pp. 7, 8, 13.

1868. *Stylocœnia emarciata*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXIV. p. 23.

Form of corallum, a convex mass; type specimen, 28 mm. in diameter on the base and 24 mm. high. The specimen is broken off from a larger piece, as Fig. 2, Plate XXXVII. shows; therefore the above measurements do not represent the original size of the corallum. Calices shallow, hexagonal, subequal in size, 1.5 mm. to 2 mm. in diameter, close together, separated by a simple wall which is from a quarter to a half millimeter thick; often there are thickenings at the corners of the calices, and remnants of what appear to have been pillars. Septa sixteen, eight large, which fuse to the columella, and eight small shorter ones. Dissepiments present, apparently numerous, very thin, in places may be close together, .5 mm. apart. The columella is styliform.

Locality. District of St. Mary, Parish of St. Mary, Point Haldane (Institute of Jamaica); Port Maria (Geological Society of London).

Type. Collection of Institute of Jamaica.

The specimen that has come under my observation does not permit a more detailed description. The description and figures seem sufficient to make the species recognizable. This is undoubtedly the same as Duncan's *Stylocœnia emarciata*, as a comparison of the above description with the notes already given on his original specimen will show. The *Stylocœnia duerdeni* seems to me distinct from *Stylocœnia emarciata*, both from the descriptions of the latter and after a comparison with specimens of the latter in the U. S. National Museum. The calices of *emarciata* are much larger, the maximum diameter being 3 mm. The usual diameter is 2.5 mm. or a little more, while in *duerdeni* the usual diameter is between 1.5 and 2 mm., with 2 mm. as a maximum. This makes a difference in size of almost a millimeter. Although the specimen of *duerdeni* is worn, in places the surface does not appear to have lost much from attrition, so one can determine the depth of the calices. They are much shallower than in *emarciata*.

MULTICOLUMNASTRÆA, gen. nov.

This genus is closely related to both *Orbicella*, Dana, and *Columnastræa*, d'Orbigny. In the description of the only known species of the genus much detail is given, so here only the more general characters will be pointed out.

Corallum, compound, one of the *Astræidæ agglomeratæ gemmantes* according to Duncan's classification. Reproduction by budding between the calices. The form ramous, or in small heads (see Duncan's *M. cyathiformis*). Corallites rather small, joined by costæ. The surface of the extra corallite area granulate, the granules placed along the costæ, which become plainly visible only in sections. Septa, in type species in three cycles, with very obscurely dentate, almost entire margins, sides granulate. Pali before the first and second cycles. The pali are small and delicate, and are not arranged in two distinct crowns, although sometimes those before the second cycle are a little nearer the wall than those of the first cycle. Endotheca present. Columella usually of several stout pillars, each having a rounded knob-like upper surface. The number of pillars varies from one to four. When there are one or two large pillars a small one or two may often be seen. In section, the pillars are joined by processes to each other and to the inner ends of the septa, so the columella in sections appears spongy, but by careful examination the pillars can be distinguished.

This genus, although it groups with *Orbicella* and *Columnastræa*, is very distinct. The surface between the corallite is very different from that of the former, and a further distinction is in the columella. *Orbicella* has a false spongy columella. In Münich, through the courtesy of Geheimerath Prof. von Zittel, I had the opportunity of studying a fine suite of *Columnastræa striata* (Goldfuss), the type species of the genus.[1] The columella in *Columnastræa striata* is a simple style. There is a single crown of six pali surrounding it, standing before only one cycle of septa. In neither of these essential generic characters does the Jamaican coral agree with *Columnastræa*; the columella of the former, as already stated, is not a single style, but consists usually of several pillars; there are not six, but twelve pali. It seems impossible to include the two in the same genus; therefore I have suggested a new generic designation for Duncan's *Heliastræa cyathiformis*.

In the following specific description there is some repetition of the descriptions of characters given in the above.

Multicolumnastræa cyathiformis (DUNCAN).

Plate XXXVII. Figs. 5-7, and Plate III. Fig. 1.

1865. *Heliastræa exsculpta*, Duncan (non Reuss), Quart. Jour. Geol. Soc. London, Vol. XXI. pp. 7, 8, 11.

1865. *Heliastræa cyathiformis*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXI. pp. 7, 8, Plate I. Figs. 1 *a*, 1 *b*.

1868. *Heliastræa exsculpta*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXIV. p. 24.

1868. *Heliastræa cyathiformis*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXIV. p. 24.

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[1] Edwards and Haime, Hist. Nat. des Coral., 1857, Tom. II. pp. 262, 263.

Corallum usually branched; the branches make a very acute angle with one another at place of bifurcation, rounded or compressed; the diameter ranges from 1 to 3 cm. One compressed branch has a greater diameter of 25 mm., and a lesser of 13 mm. The ends of the branches are rounded, sometimes swollen. An aberrant and unusual form is that of the specimen figured by Duncan as the type of *Heliastræa cyathiformis*. This specimen is expanded above and excavated in the central portion so that it has some resemblance to a cup. The calices project very slightly or not at all above the extra corallite areas. Their diameter is 2 mm., and the distance apart 1 to 1.5 mm. The extra corallite portion of the corallum densely granulate, the granules rounded or elongate and arranged along the summits of flexuous costæ, which are not distinct on the unworn surfaces. Corallites joined by costæ. Calicular fossa shallow. The septa are crowded, and the upper margins form a little rim that contrasts strongly with surrounding granulate area. There are three complete cycles. The first and second cycles are usually indistinguishable in size, both reach far into the corallite cavity and have pali on the inner terminations. The margins are slightly dentate. The columella is variable. It consists of one, two, three, or four stout pillars, each with a rounded upper surface. Endotheca well developed, the dissepiments are fine and close together.

Localities. Catadupa, Jamaica (R. T. Hill, collector); Mount Hindmost, District of Clarendon, Parish of Clarendon (Jamaica Institute collection).

Notes. The results of the study of the type of Reuss's *Heliastræa exsculpta*, of the original specimens of Duncan's "*H. exsculpta*," and of the type of Duncan's *Heliastræa cyathiformis*, have already been given in the Introductory remarks.[1] Duncan's specimens of "*Heliastræa exsculpta*" are of the same form as Plate (so called) are not the species of Reuss at all, but are branches of his own XXXVII. Fig. 5 of this paper. His *Heliastræa cyathiformis* is only an abnormal form (i. e. it possesses an abnormal shape) of the same thing. The calices, etc. are identical in the two. Duncan's figure of the calices of *Heliastræa cyathiformis* is extremely misleading.

Additional Localities. Duncan had specimens from Trout Hall, Mount Hindmost, and Cupuis identified as *Heliastræa exsculpta*. The specimens from the first two places are without any doubt *Multicolumnastræa cyathiformis*. The specimen from Cupuis is worn, and I could not identify it positively without sections, but it seems to be the same species as the other specimens.

The type of *Heliastræa cyathiformis* is from Trout Hall.

STIBORIOPSIS, gen. nov.

Corallum massive, heavy, subplane above. Septa solid, imperforate, dentate, pali or paliform lobes before the principal septa. Endothecal dissepiments abundant. Wall formed by the fusion of the distal ends of septa. Columella spongy, with a papillary upper termination. Reproduction by septal budding and fission. The calices form short series, with two to four distinct calicinal centres. In many places on the upper surface of the corallum the walls of neighboring series seem fused together, but in more eroded places the walls appear distinct. In the section represented in Plate XXXVIII. Fig. 4, it is distinctly shown that the walls of the series are not fused, but that the corallites are joined to each other by their costæ. There appears to be some exotheca..

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[1] Vide *ante*, p. 228.

Three other genera seem closely related to the one here characterized. The first is *Stiboria* of Étallon. The following is the original description :[1] "Polypier massif, étroitement fixé, en lames peu épaisses; les séries d'assez faible longueur; calices doubles, plus ou moins tortueux, séparés par un sillon assez étroit, au fond duquel on aperçoit plusieurs séries de granulations ; tissu peu compacte. Centres complètement indistincts, pas de columelle. Les cloisons dentées seulement près du centre ; une épithèque." The points of difference are, 1st, the series in *Stiboriopsis* are not separated by a furrow; 2d, the calcinal centres are distinct; 3d, there is a spongy columella, with a papillary upper surface, as stated in the description.

The genus is also closely related to *Symphyllia*, Edwards and Haime, and *Isophyllia* of the same authors; but both of the genera have the septa strongly spined, whereas *Stiboriopsis* has simply dentate septa.

Stiboriopsis jamaicaensis, sp. nov.

Plate XXXVIII. Figs. 2–4.

The details already presented need not be repeated. The specimen upon which the genus and species are based is a mass 89 mm. long, 63 mm. wide, and about 45 mm. thick. As the specimen has been subjected to some rolling, it originally was larger. The upper surface is subplane, slightly convex. Solitary calices have a diameter of 7 to 9 mm. One series of three calices measures 15 mm. long and about 5 mm. wide ; another of four calices is 20 mm. long and 5 to 7 mm. wide. The thickness of the walls, with interspace between the series, is from 1 to 2 mm. The series are rather straight, very slightly flexuous. The valleys are not very deep, and are widely open. The septa are only moderately stout and are not greatly crowded. A solitary calice about 8 mm. in diameter has about thirty-six septa, alternately large and small. This would be three complete cycles, with twelve members of the fourth. This septal arrangement is common. The various systems and cycles are not distinctly differentiated. The teeth on the septal margins could be seen on only a few septa, but they are not coarse. The inner terminations of the large septa are swollen, and bear paliform teeth. The swollen ends and paliform lobes make a sort of crown surrounding the columellar termination. The upper end of the columella is in a depression surrounded above by the crown. These swollen ends of the septa sometimes fuse laterally with one another. The sides of the septa are beset with crowded pointed granules. Endothecal dissepiments very abundant; in the cross section of one interseptal loculus seven were counted; usually at least three are present in each cross section of the loculi. The dissepiments are thin.

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[1] Lethea Bruntrutana, 1863, p. 386; see Plate LVII. Fig. 1. The date of this work is a little uncertain. The Geological Society of London Catalogue gives it as 1861.

Locality. Craigie, Parish of Hanover.

Type. Collection of Institute of Jamaica, Kingston, Jamaica.

DIPLORIA, EDWARDS AND HAIME.

In examining the literature on *Diploria* I find that certain of its features are so vaguely described that one is likely to fail to recognize the genus. In characterizing the genus Edwards and Haime state, "la columelle est spongieuse, essentielle et bien développée."[1] Duncan's description of the columella in his "Revision of the Families and Genera of the Madreporaria,"[2] is merely a translation of the original French. In examining specimens of the species of *Diploria* herein described, of *D. crassolamellosa*, Edwards and Haime, and from figures of *D. flexuosissima*, d'Achiardi, the persistent presence of a lamellar columella was noticed.

In the first characterization of *Diploria*,[3] only the *Mœandrina cerebriformis* of Lamarck is mentioned, so this species, the common *Diploria cerebriformis* of the West Indies, is the type of the genus. A study of this species has shown that it possesses a lamellar columella, which is given a spongy appearance in places by the inner termini of some septa fusing to it and sending out some processes in the axial space. The columella is not continuous throughout the whole length of a series, but is broken here and there by what probably are calicinal centres. A section of one series parallel to the septal planes showed a perfectly distinct lamellar columella through a vertical distance of 1 cm. This was the length of the section.

The usual definition of *Diploria* must be modified so as to include the observations above noted.

Diploria confertiocostata, sp. nov.

Plate XXXIX. Figs. 1-3.

1865. *Diploria crassolamellosa*, Duncan (non Edwards and Haime) Quart. Jour. Geol. Soc. London, Vol. XXI. pp. 7, 12.

1868. *Diploria crassolamellosa*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXIV. p. 24.

[1] Hist. Naturelle des Coralliaires, 1857, Tom. II. p. 401.

[2] Journ. of the Linn. Soc. (Zoöl.), 1884, Vol. XVIII. p. 88.

[3] Comptes Rendus de l'Acad. des Sc. (Paris), 1848, Tom. XXVII. p. 498.

An examination of the original specimens of Duncan in the collection of the Geological Society of London proved that the specimens collected by Mr. Hill at Catadupa are identical with the *Diploria crassolamellosa* of Duncan, which a study of *Diploria crassolamellosa*, Edwards and Haime, showed to be an entirely different species.

Form, flat, lobed, or subglobose masses. The largest specimen examined (from the Institute of Jamaica collection) is 80 mm. long, 64 mm. wide, and 51 mm thick. The series are very long, narrow, and flexuous; one series may wind around over nearly the entire upper surface of the specimen. The valleys are elevated above the collines, — i. e. the depression between the series is quite deep, sometimes as much as 2 mm. The width of the series is from .5 to 1.5 mm.; 1 mm. is a fair average; the distance between the series is from 1.5 to 3 mm. The whole upper extraserial surface of the corallum is covered with very fine, low, acute equal costæ, with granulations on the edges. There are 45 to 48 costæ to the centimeter. The septa correspond to the costæ in position and number; they are very crowded, are of the same size, or are alternately slightly larger and smaller. Their upper edges but little elevated, falling in a convex curve to the bottom of the calicular furrow, which is very narrow. Dissepiments are quite numerous. The columella is lamellar, broken here and there by calicinal centres. In longitudinal section it can be seen that the inner edges of the septa fuse by processes placed one above the other to the columella.

Localities. According to Duncan, Trout Hall and Upper Clarendon. R. T. Hill's collection, Catadupa. A specimen from the Institute of Jamaica is from the District of Clarendon, Parish of Clarendon.

Types. Museum of Comparative Zoölogy, Harvard University, and Institute of Jamaica; specimens in collection of the Geological Society of London.

Remarks. It is difficult to see how Duncan ever identified this species with *D. crassolamellosa*, as Edwards and Haime state: "Largeur des vallées, 3 millim. On compte environ 18 cloisons dans la longeur d'un centimètre."[1] As already noted, the width of the valleys in *D. conferticostata* is .5 to 1.5 mm., and there are 45 to 48 septa to the centimeter. The species are only generically related. But the Jamaican form is extremely closely related to *Diploria flexuosissima*, d'Achiardi,[2] from the Eocene of San Giovanni Ilarione, Italy. In fact they are so near each other that I thought at first the Jamaican form must be considered identical with the Italian form. Reuss[3] has published a good figure of *D. flexuossissima*, and made some critical notes. For purposes of comparison the greater part of Reuss's description is quoted: "Die Oberfläche ist mit schmalen und seichten, sehr langen, vielfach gewunde-

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[1] Hist. Nat. des Corall., Tom. II. p. 405, 1857.

[2] Corallarj Fossili del Terreno Nummulitico dell' Alpi Venete, Mem. della Soc. Ital. di Sc. Nat., Tom. IV. No. 1, 1868, p. 26, Plate XI. Fig. 4.

[3] Denksch. d. Wiener Akad. der Wissensch. (Math.-Wiss.), Bd. XXXIII. p. 11, Plate XXXIX. Fig. 1, 1874.

nen Sternreihen bedeckt, die einen Querdurchmesser von 2–3 Millim. besitzen. Sie werden durch wenig tiefe Zwischenfelder getrennt, die in der Regel eben so breit sind als die Thäler und nur stellenweise, besonders an Punkten stärkerer Krümmung, sich mehr ausbreiten oder im Gegentheile verengern. Sie sind mit gedrängten, wenig ungleichen Rippchen besetzt."

The columella is practically the same as in *D. conferticostata*, sometimes appearing somewhat spongy. "Die Septallamellen sind gedrängt und dünn, an Dicke wenig ungleich. Zwischen zwei längere findet man jedoch fast regelmässig eine viel kürzere eingeschoben. Die längeren verdicken sich in der Nähe der Axe zu einem starken Knötchen, das sich mit den benachbarten verbindet. Die dadurch entstehende Knötchenreihe wird von der Axenlamelle durch eine ziemlich tiefe Furche geschieden. In der Lange eines Centimeters zählt man etwa 44 Septallamellen."

From this description three points of difference become apparent: 1st, the valleys in *D. conferticostata* are only about half as wide as in the species from San Giovanni Ilarione; 2d, in the former there is not that alternation of longer and shorter septa characteristic of the latter; 3d, in the Jamaican species there is no series of fused knobs, corresponding to the inner termini of the larger septa, on either side of the columella, and separated from it by a rather deep furrow. After having made this comparison, it will be easily seen that the two species are very distinct; but the features that they have in common show them to be closely related.

Diploria conferticostata, var. columnaris, var. nov.

Plate XXXIX. Fig. 4.

In the preceding discussion, I have purposely omitted the consideration of a specimen that seems to me to be a young one of *D. conferticostata*, with a different mode of growth. The form is a short ascending column, about 38 mm. high, with the following dimensions. 28 mm. below the top: greater diameter, 18 mm.; lesser, 12.5 mm. At the top the specimen is compressed and has begun to bifurcate. Here the greater breadth is 22 mm.; the lesser varies from 2.5 to approximately 10 mm. The 10 mm. is the thickness of the thicker branch. The series are very long and much wound. The distance across the valleys is 1 to 1.5 mm.; across the collines about .5 mm. There are about 30 costæ or septa to 5 mm., — 60 to the centimeter. The depression on the summit of the colline is usually very obscurely or not at all marked; in some places it is moderately distinct. These are the points of difference. The specimen is evidently immature, and I am confident that it is only a yonng, somewhat peculiar variety of the *D. conferticostata*.

Locality. Catadupa, R. T. Hill, collector.

Type of Variety. Museum of Comparative Zoölogy, Harvard University.

TROCHOSERIS, Edwards and Haime.

Trochoseris catadupensis, sp. nov.

Plate XXXIX. Figs. 5, 6.

Corallum short cornute, attached by a pedicel, calice flaring out. Height of corallum 13 mm. Diameters 3 mm. below calicular margin: longer, 12 mm.; shorter, 10 mm. Diameters of calice: greater 16 mm.; lesser 15.5 mm. The outer surface marked by low subacute costæ, alternately larger and smaller in size, with granulated or dentate margins. The wall, where it could be cleaned, showed no perforations. The exact number of septa could not be made out with absolute certainty; by counting costæ and septa where not broken off, 140 seemed to be the number, — i. e. there are five complete cycles with about half the members of the sixth. To be sure, the septa are much crowded together. The members of the first, second, and some of the third cycles reach the columella; those of the higher anastomose to the lower after the type of junction in *Trochoseris distorta* (Michelin). The septa are solid, their sides are granulate, and their margins appear to be dentate. Synapticulæ present in the interseptal loculi. The interseptal loculi filled up with calcareous deposit. The calicular fossette in the axial region is narrow and moderately deep. The columella is small, rather deep seated. It appears to be composed of several trabeculæ. The characters of the columella could not be made out as fully as was desired, but one is present, though it is small.

Locality. Catadupa (R. T. Hill, collector).

Type. Museum of Comparative Zoölogy, Harvard University.

Remarks. The specimen on which this species is based is apparently well preserved, but on account of the calcareous filling of the lower portion and the indurated condition of the matrix, calcareous sand and clay, many hours of study were necessary before the features embodied in the above description could be discovered. The description is not so full as is desirable, but in every essential feature the species coincides generically with *Trochoseris*, as a very careful comparison with *T. distorta* showed, and as it is peculiar for the West Indies, it should be easy to recognize it hereafter.

LEPTOPHYLLIA, Reuss.

Leptophyllia agassizi, sp. nov.

Plate XL. Figs. 1-4.

Form of corallum: only one piece, with a few attached very young individuals, has been submitted to me. This piece is 27 mm. long; on the lower end the greater diameter is 14 mm., the lesser 12.5; on the upper end the cross section is practically circular, and is about 17 mm. in diameter. The base of one attached young individual measured, greater diameter, 7 mm.; lesser, 5 mm.; height, 3.5 mm. The base may be larger or smaller, judging from other imperfect young. From these data, the corallum is tall, subclavate, gradually enlarging upward, attached by a moderately large base, with a slightly elliptical cross section. Strictly speaking, there is no wall, the septa joined in their distal portions by numerous synapticulæ. Externally the corallum is ornamented by very many very fine costæ (the peripheral ends of the septa). The costæ show sometimes a faint, sometimes a distinct, alternation in size; the edges are granulate. Between the costæ are numerous delicate synapticulæ. There is no epitheca. Septa very crowded, numerous; 144 were counted on the smaller end of the type; some small ones may have been overlooked. There are five complete cycles, and many members of the sixth. There is some anastomosing among the septa, the 1st, 2d, and 3d cycles reaching the axial space. The septa are very thin, very perforate, and synapticulæ are very abundant in the peripheral portion of the corallum, making a good substitute for a wall. Dissepiments may be present. I was unable to determine this. On the sides of the septa, pointed granulations are quite frequent. There is no true columella, but a few processes from the larger septa form a very lax and very insignificant false one. The calice in the specimen has been destroyed, but it can be seen that the fossa was moderately deep.

Locality. Solomon Mountain, west of Mint, Westmoreland Parish (R. T. Hill).

Type. Museum of Comparative Zoölogy, Harvard University.

Remarks. Every character of the coral seemed to agree with those of *Leptophyllia.* For a description of the detailed characters of the genus, Pratz's "Ueber den Aufbau des Septalapparates einiger charakteristischer Gattungen" should be consulted.[1]

TURBINOSERIS, Duncan.

Much difficulty has been experienced in trying to place generically the two corals next to be described. This difficulty has arisen from the insufficiency of the original characterization of the genus. Duncan proposed the genus[2] for a new species called by him *Turbinoseris de-fromenteli* from the Lower Greensand, giving the following generic diagnosis: "The corallum is simple, more or less turbinate, or constricted midway between the base and calice. The base is either broad and adherent, or small and free.

"There is no epitheca, and the costæ are distinct.

"There is no columella, and the septa unite literally [*sic*, laterally], and are very numerous."

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[1] Palaeontographica, 1882, Bd. XXIX. pp. 90–92.

[2] Monograph Brit. Foss. Corals, 2d series, Palæontog. Soc., Vol. for 1869 (1870), pp. 42, 43, Plate XV. Figs. 13–18.

In describing the species, two additional characters of importance are stated: "The synapticulæ are well developed," and "The costæ are well developed, and often not continuous with the septal ends." No discussion of the character of the wall is given, but both Figures 13 and 14, Plate XV., represent a perforate or synapticulate composition. Figure 18 of the same plate illustrates the noteworthy condition of the costæ alternating with the septa. Figure 16, representing a calice natural size, shows an apparently imperforate wall, though not of uniform thickness, and the septa in the majority of cases corresponding in position to the costæ. The type species needs a new study, and we cannot have a clear conception of its characters until this is made.

Duncan, in his paper on the St. Bartholomew corals,[1] described six species that he referred to *Turbinoseris*, but no additional data on the generic characters are given. He speaks of the wall being "thick" in most of the species, and both mentions and figures synapticulæ between the costæ.

He considers the genus again in his Revision of the Genera of the Madreporaria,[2] but, excepting the statement that the septa are solid and the wall stout, no additional information is given. The genus is classed in the "*Lophoseridæ*," "Funginæ in which the wall is neither perforate nor echinulate," etc.[3]

From a comparison of the figures of the two species herein described with those of the species of *Turbinoseris* from St. Bartholomew, given by Duncan in Volume XXIX. of the Geological Society of London, the generic identity of the forms is most apparent. The only possible opportunity for error would be in the wall of the St. Bartholomew corals being imperforate, but I cannot believe this with Duncan's figures before me. Therefore I have referred the two Jamaican corals to *Turbinoseris* on the strength of their resemblance to the species from St. Bartholomew, but whether Duncan was correct in referring the latter corals to that genus must be left to future work.

Especial attention should be called to *Turbinoseris jamaicaensis*, as, besides the synapticulæ between the distal ends of the septa, quite often the septal ends are solidly united by a thecal or pseudo-thecal thickening.

The similarity in the general structural features of these two species to that of *Leptophyllia* deserves a note. The septal structure (i. e. the septa are composed of ascending trabeculæ) is the same, except that in the species of *Leptophyllia* the trabeculæ are not fused together to a great extent, whereas in *Turbinoseris* the fusion is so complete or so nearly complete and septal perforations are so rare that the septa can best be considered solid. The character of the columella and that of the wall (or absence of wall) in both are respectively of the same type, the latter structure in *Turbinoseris* is not so loose as in *Leptophyllia*, and, as already stated, in *Turbinoseris* there is in places theca or pseudo-theca. The typical species of *Leptophyllia* are attached by broad bases.

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[1] Quart. Jour. Geol. Soc. London, 1873, Vol. XXIX. pp. 558–561.

[2] Jour. of the Linn. Soc. (Zoölogy), 1884, Vol. XVIII. p. 148.

[3] *Op. cit.*, p. 146.

Turbinoseris cantabrigiensis, sp. nov.

Plate XL. Figs. 5-7.

Form compressed, conical, attached by a very small pedicel. Measurements of two specimens give the following : —

	Height of Corallum.	Greater Diameter of Calice.	Lesser Diameter of Calice.
a (figured type)	18.5 mm.	10.0 mm.	6 mm.
b	15.0 mm.	11.5 mm.	8 mm.

The costæ are very fine, crowded, not prominent and acute, alternating in size. The wall is synapticulate. There is no wall properly speaking, but the many synapticulæ near the peripheral ends of the septa serve as one. Of course, perforations between the distal ends of the septa are frequent. The septa are composed of ascending trabeculæ; the fusion between them seems sometimes, but very rarely, incomplete, leaving pits or occasional perforations. The septa are very numerous, extremely thin, and very much crowded; not thickening at the centre. The type has between 80 and 90 septa; the other specimen, whose measurements are given above, has five complete cycles, apparently 99 septa. Some septa of the higher cycles fuse by their edges to the sides of the members of the lower cycles. Calice rather shallow. Strictly speaking, there is no columella, a few septa fuse loosely in the axial space.

Locality. Near Cambridge, south of Montpelier, St. James Parish, Jamaica (R. T. Hill, collector).

Remarks. The species above described is very close to Duncan's *Turbinoseris eocænica*,[1] from the limestone of St. Bartholomew. I have been unable to see the types of the species from St. Bartholomew, as they are in Stockholm and Upsala, therefore the following comparison is based on the original description. There are two points of difference. *The first* is one of size. Duncan gives the size of *T. eocænica*, "Height of full grown specimen 1 inch (= 25 mm.). Length of calice $\frac{7}{10}$ inch (= 18 mm.). Breadth $\frac{4}{10}$–$\frac{5}{10}$ inch (= 10 to 12.5 mm."[2] *T. eocænica* is a much larger species. Duncan states that there are five cycles of septa with some members of the sixth in the species; therefore the septa in *T. cantabrigiensis* are necessarily more crowded. *The second* difference concerns the inner terminations of the septa. Duncan says that in *T. eocænica* the ends of the larger septa are swollen, and bound the axial space. As stated above in its description, *T. cantabrigiensis* does not have the ends of the larger septa so swollen. The two species are close, but appear distinct. Duncan's Figure 12, Plate XXI., of the costal synapticulæ in *T. eocænica* would apply equally well to *T. cantabrigiensis*.

[1] Quart. Jour. Geol. Soc. London, 1873, Vol. XXIX. p. 558, Pl. XXI. Fig. 12.

[2] I have inserted the approximate equivalents in millimeters.

Turbinoseris jamaicaensis, sp. nov.

Plate XL. Figs. 8-10.

Corallum subconical, tip of base a small nipple-like pedicel. Height of corallum, 19.5 mm.; greater diameter, 15 mm.; lesser, 13.5 mm. The external surface covered with small, densely crowded granulate costæ, alternately larger and smaller in size; synapticulæ abundant between them. The wall is for the greater part synapticulate and perforate, but in places it is solid to a greater or less extent. Septa very numerous and very much crowded; there are over 100, so there are more than five cycles, but the sixth is not complete; their margins apparently finely dentate; the septa of the lower cycles are thicker around the axial space than peripherally. The calicular fossa is narrow and deep. There is no columella, but some of the principal septa meet in the axial space.

Locality. Near Cambridge Station, south of Montpelier, St. James Parish (R. T. Hill, collector).

Type. Museum of Comparative Zoölogy, Harvard University.

Remarks. This species differs from the preceding, *T. cantabrigiensis*, by its more robust form, and the inner thickening of the larger septa. The calicular fossa is deeper and narrower. It is closer to *T. eocænica*, Duncan, from which it differs in its form. The axial ratio for *T. eocænica* is $\frac{\text{10-12.5 mm.}}{\text{18 mm.}}$; for *T. jamaicaensis*, $\frac{\text{13.5 mm.}}{\text{15 mm.}}$; the former is much more compressed laterally.

It is evident that *T. cantabrigiensis* and *T. jamaicaensis* are very close to each other, and both are extremely near to *T. eocænica*, but as differences of considerable importance exist between all three of the forms, it is best to regard them as specifically distinct.

MESOMORPHA, Pratz.

Mesomorpha catadupensis, sp. nov.

Plate XLI. Figs. 1-3.

Corallum depressed, flat above, transverse outline, subelliptical. Measurements: height (thickness), 7 mm.; greater distance across, 26 mm.; lesser distance across, 24 mm. The base of the corallum has on it some concentric folds, and there is an incomplete epitheca. The costæ are low, equal, and have synapticulæ between them. The outer or common wall probably is synapticulate, i. e. probably there is none, strictly speaking. The calices are concentrically arranged. In the centre is a larger calice, outside of it are two concentric rings, and near the edge of the corallum some small calices belonging to a third one. From the central calice to the calices of the first ring is 5.25 mm. The calices in the first ring are usually 4 mm. apart. There is a slight variation above and below this number. The distance between the first ring and the second ring of calices is from 3 to 5 mm. The distance between calices in the second ring is usually 3 mm. The septo-costæ are directly continuous from one calice to the other, and there is no indication of any sort of bounding wall between the calices. The septa are thick, very close together, the number in the larger calices is twenty-nine to thirty. There is considerable anastomosing between them. The margins are formed by series of roundish or squarish knots. The septa are composed of ascending moniliform trabeculæ, which are slightly inclined inward. The upper terminations of the trabeculæ make the knots on the septal margins. The fusion of adjoining trabeculæ is apparently complete, so the septa are solid except occasionally just below their upper margins. Synapticulæ are abundant. No dissepiments were seen. Calices wide open, not very deep. In the columella space are a few papillæ.

Locality. Catadupa (R. T. Hill, collector).

Type. Museum of Comparative Zoölogy, Harvard University.

Remarks. The generic determination of this species, and also one already mentioned as coming from the Midway (basal Eocene) beds of Alabama, has given me enormous trouble. There is no way of distinguishing from the literature the difference between *Mesomorpha* and *Thamnastræa*, because no thorough study of the type of the latter genus, *Thamnastræa dendroidea* (Lamouroux), has been made. Pratz in his memoir, "Ueber den Aufbau des Septalapparates einiger charakteristischer Gattungen,"[1] does not even mention the type species. So, although Pratz has added some interesting observations on the septal structure of some corals, he has not informed us what *Thamnastræa* really is. He has not given the name of the species on which he based his figures and studies, therefore we do not know that he studied *Thamnastræa* at all.

According to Pratz's figure of *Mesomorpha*,[2] apparently the species under consideration must belong to that genus, but it is impossible to decide whether it is a *Thamnastræa*. The following is Pratz's definition of *Mesomorpha*:[3] "Polypar massiv, knollig, höckrig oder ästig, zuweilen incrustirend. Kelche niedrig, nicht durch scharfe Grate umschrieben, sondern durch Septocostalradien untereinander verbunden. Eine mauer fehlt oder ist höchtens rudimentär und von den Septocostalradien versteckt. Septa compact, an den Seitenflächen mit Körnern versehen. Die benachbarten Septalflächen sind durch starke, echte Synaptikeln mit einander verbunden. Letztere verleihen dem zwischen den Kelchcentren befindlichen Sclerenchym bei unregelmässigem Verlaufe des Septocostalradien zuweilen ein Coenenchym-artiges Aussehen. Der Septalrand ist regelmässig gekörnelt und deutet auf einen trabeculären Aufbau hin. Säulchen papillär häufig mit mehreren Sternleisten verschmolzen." There

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[1] Ueber die verwandschaftlichen Beziehungen einiger Korallen Gattungen. Palaeontographica, 1882, Bd. XXIX. pp. 92–98.

[2] Eocäne Korallen aus der Libyschen Wüste und Aegypten, Palaeontographica, Bd. XXX., 1883, Pal. Theil, pp. 226–227, Pl. XXV. Figs. 45, 45*a*.

[3] Eoc. Korall. aus der Lib. Wüste, etc., *loc. cit.*

might be two reasons for questioning my generic reference: the first is, I have not stated whether the synapticulæ are true or false. As no thin section was made, this point of structure could not be determined. But I do not believe in the systematic value of dividing synapticulæ[1] into true and false. Whether the synapticulæ are true or false depends largely upon spacial relations, as do many other microscopic features of the coral skeleton. If the septa are crowded the synapticulæ are apt to be false, while if they are more remote from each other the synapticulæ are apt to be true. Figure 71, in Miss Ogilvie's "Microscopic and Systematic Study of Madreporarian Types of Corals,"[2] is a good illustration of this. This figure represents two adjoining septa of *Siderastræa*. Near the peripheral ends of the septa the synapticulæ are true, i. e. there are new calcification centers introduced to effect the junction of the opposing septal granulations; whereas, near the inner ends of the septa, where the opposing septal surfaces are close together, no additional centers of calcification are needed to make the junction of the granulations, so they fuse directly and form a pseudo-synapticula.

Probably another note should be added on the septal structure. The trabecular composition has already been noted. In the lower part of the calices the trabecular fusion seems perfect, but near the septal margins the fusion apparently may quite often be incomplete. Here pits are very distinct on the flat surfaces of the septa, should the septa be not completely perforated. This might be a second reason for the removal of the species from *Mesomorpha*.

It was not determined whether dissepiments are present or not.

Species of *Mesomorpha* occur in the Gosau Cretaceous and in the Eocene of the Arabian Desert. Pratz is of the opinion that *Thamnastræa ferojuliensis*, d'Achiardi, from the Italian Eocene, and *Thamnastræa balli*, Duncan, from the lower Eocene of India, also belong to this genus.

DENDRACIS, Edwards and Haime.

Dendracis cantabrigiensis, sp. nov.

Plate XLI. Figs. 4-6.

The corallum is composed of small slender branches from 3.5 to 8.5 mm. in diameter. The branch 3.5 mm. in diameter is 26 mm. long. There is no means of knowing to what length the thicker branches will attain. The calices are distributed in rather regular spirals; the usual diameter is 1 mm., and the distance apart also usually 1 mm. On very small branches some calices may have a diameter very slightly less than a millimeter, and may be a little more than a millimeter apart, but the average is as first stated. The calices on the upper side are not at all elevated above the cœnenchyma, but on the lower side they stand about 1 mm. above it. The outside of the projecting part of the corallite has distinct equal costæ corresponding to each septum. I observed no perforations between the costæ. The cœnenchymal surface is densely and minutely granulate; when the outer surface is worn away its porous nature is revealed. Septa : there are six septa larger and more prominent than the others; in each well preserved calice examined, *between each pair of larger septa is a pair of smaller septa.* The septa are stout, so far as could be made out solid, imperforate, and have entire margins. There is no columella.

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[1] Consult G. von Koch: "Das Skelett der Steinkorallen," Festschrift für Carl Gegenbauer, 1896, p. 260.

[2] Phil. Trans. Roy. Society, 1896, Vol. 187, p. 244.

Locality. Near Cambridge Station, south of Montpelier, St. James Parish, Jamaica (R. T. Hill, collector).

Types. Museum of Comparative Zoölogy, Harvard University.

Remarks. This species has considerable resemblance to *Dendracis haidingeri*, Reuss, from Oberburg, Steiermark,[1] also found at Castel Gomberto, Monte Grumi and Monte Viale, Italy. Felix[2] reports it from Gebel Auwēbet, Egypt. The following notes made on specimens in the Vienna Hofmuseum show the differences. The calices of *D. haidingeri* tend to be constricted above. There are two complete cycles of septa, with members of the third cycle sometimes present. On the lower side of the projecting part of a corallite there are two or more costæ for each septum.

PORITES, LAMARCK.

Porites reussiana, DUNCAN.

1865. *Porites reussiana*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXI. p. 8 (original description), Pl. I. Fig. 2. Another reference, p. 7.

1868. *Porites reussiana*, Duncan, Quart. Jour. Geol. Soc. London, Vol. XXIV. p. 25.

Original Description. "The corallum is in more or less cylindrical branches, which leave the stem at an acute angle, and are often flattened, and always rugged and gibbous. The calices are large, irregular in size, and shallow. The columella is small, and there are sometimes more than six distinct pali. The septa are from eight to twenty-four in number. Diameter of calices often $\frac{1}{10}$ inch; that of the branches from $\frac{6}{10}$ to $\frac{18}{10}$ inch.

" *Locality.* Upper Clarendon District, Jamaica."

I saw the type in the collection of the Geological Society of London, and add a few notes to the above description. The usual number of cycles of septa is three; the arrangement into cycles does not appear perfectly regular and uniform, so Duncan's figures must be used with a qualification. In the best preserved portions there is no granulate area on the summit of the wall between the ends of the septa. Apparently the upper edge of the wall is acute in perfect material. Diameter of the calices 2.5 to 4 mm.; the usual diameter is slightly less than 3 mm. The specimen does not permit the details of the pali (?) to be made out. It seems quite probable that the species is a *Litharœa*, and not a *Porites*.

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[1] Denkschrift d. Wiener Akad. d. Wissenschaft. (Mat. Natur.), Bd. XXIII. 1st Abtheil, 1863, p. 27, Pl. VIII. Figs. 2–5.

[2] Felix, Zeitschrift d. deutsch. geolog. Gesellschaft, 1884, Bd. XXXVI. p. 424, Pl. III. Fig. 12.

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PLATE XXXIX.

Figs. 1–3. Diploria conferticostata, sp. nov. Figs. 1 and 2, views of two different coralla, natural size; Fig. 3, 1 cm. of a series on specimen represented by Fig. 1, enlarged.

Fig. 4. Diploria conferticostata, var. columnaris, var. nov., natural size.

Figs. 5, 6. Trochoseris catadupensis, sp. nov. Fig. 5, view from side; Fig. 6, view of calice; both natural size.

PLATE XL.

Figs. 1–4. Leptophyllia agassizi, sp. nov. Fig. 1, general view of specimen; Fig. 2, costæ enlarged, shows their trabecular nature and some synapticulæ between them; in many instances at the surface the trabeculæ are not fused together, in others they are; synapticulæ are more abundant than is represented; Fig. 3, a portion of a cross section magnified 3⅓ times; Fig. 4, several septa more highly magnified, to show the synapticulæ. It is doubtful if there are any dissepiments, though some may be present.

Figs. 5–7. Turbinoseris cantabrigiensis, sp. nov. Fig. 5, view from side, natural size; Fig. 6, costæ (peripheral ends of the septa) enlarged, to show the synapticulæ between them; Fig. 7, portion of a section of a corallum to show synapticulæ between septa, magnified about 8 times. There also appear to be occasional perforations near the inner terminations of the septa.

Figs. 8–10. Turbinoseris jamaicaensis, sp. nov. Fig. 8, view of specimen from side, natural size; Fig. 9, view of calice from above, 1⅔ natural size; Fig. 10, costæ (peripheral ends of septa) magnified to show synapticulæ between them.

PLATE XLI.

Figs. 1–3. Mesomorpha catadupensis, sp. nov. Fig. 1, view from above; Fig. 2, view of corallum in profile, both natural size; Fig. 3, several calices, magnified nearly 3 times.

Figs. 4–6. Dendracis cantabrigiensis, sp. nov. Fig. 4, a fragment of a rather thick branch; Fig. 5, a young slender branchlet; both natural size; Fig. 6, several corallites and surface magnified.

THE HELIOTYPE PRINTING CO BOSTON

TYPICAL BLUE MOUNTAIN SCENERY, ROAD TO CASTLETON.

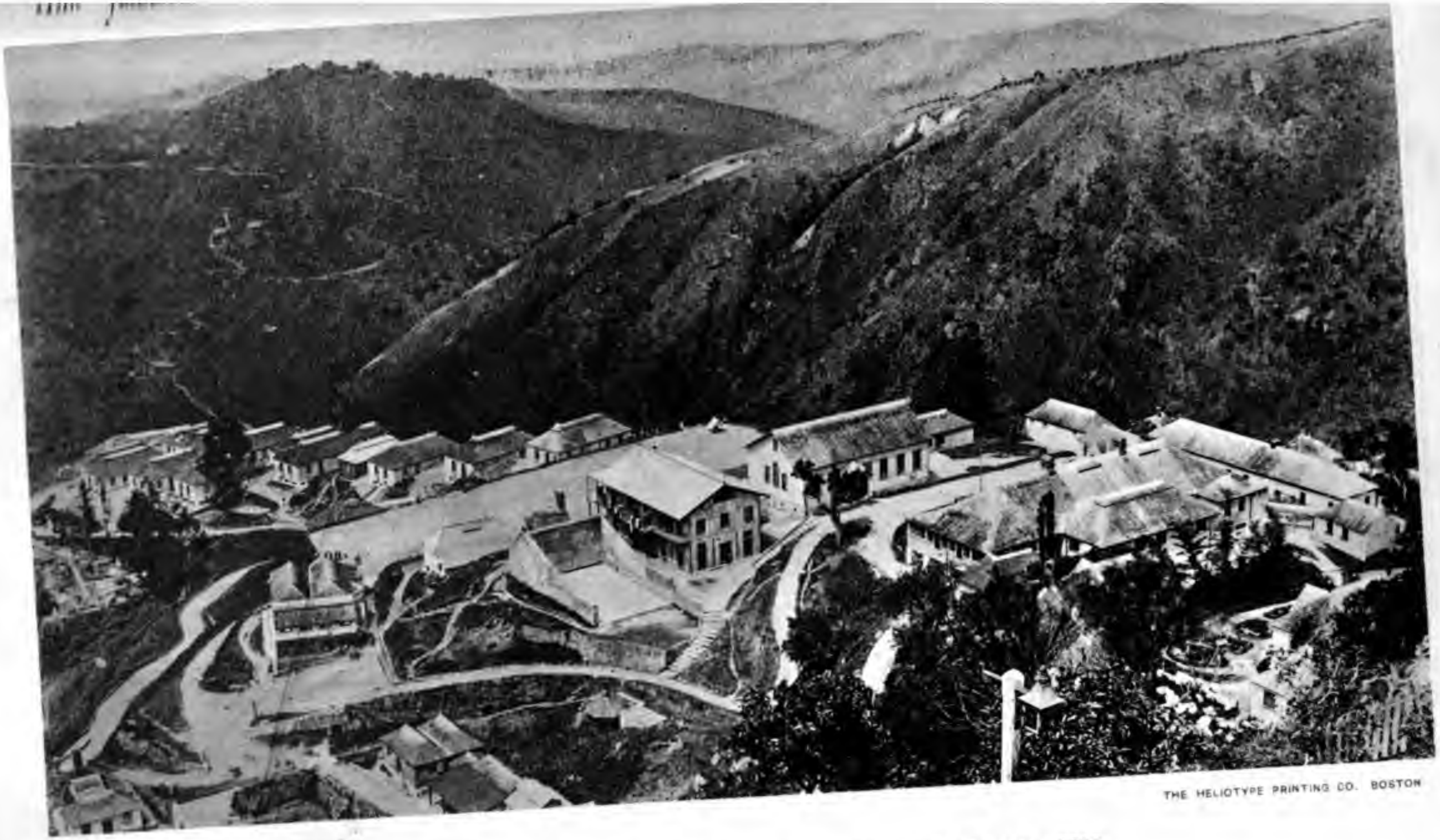
1

St. Catherine Peak.

2

Up the Blue Mountains.

THE HELIOTYPE PRINTING CO. BOSTON



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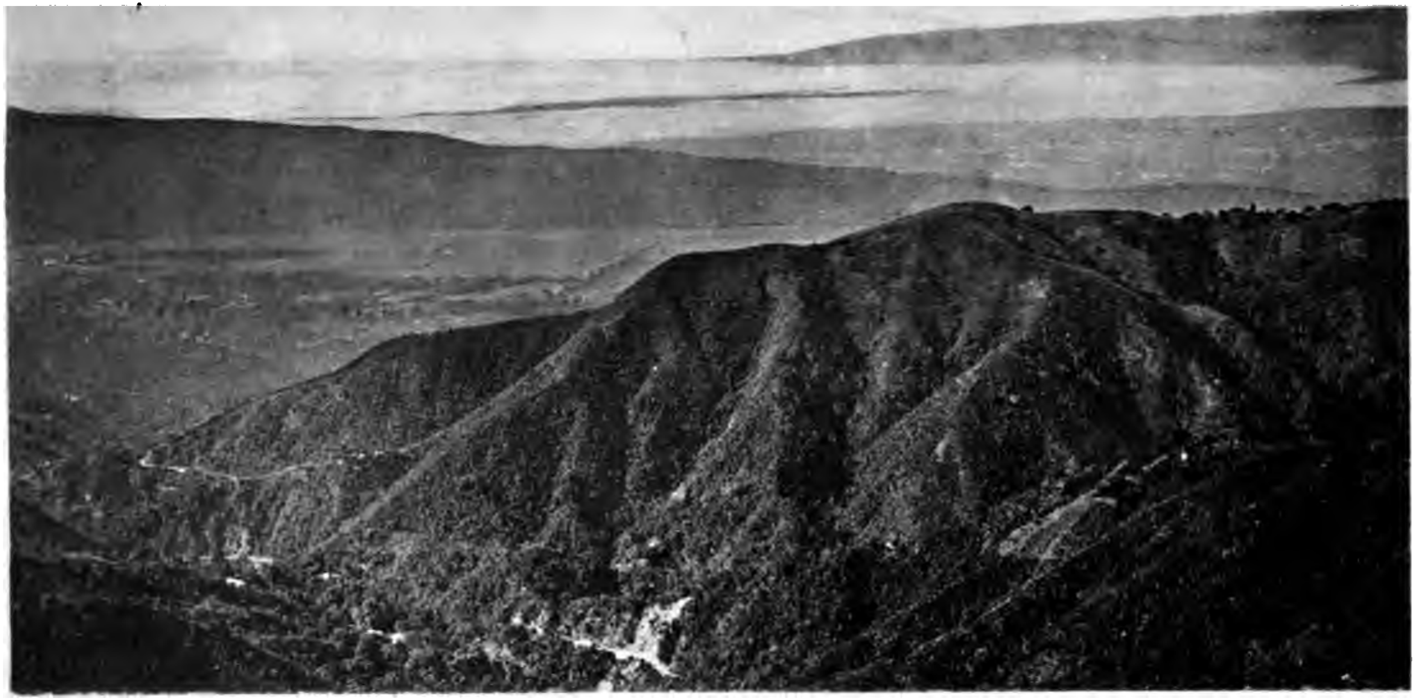
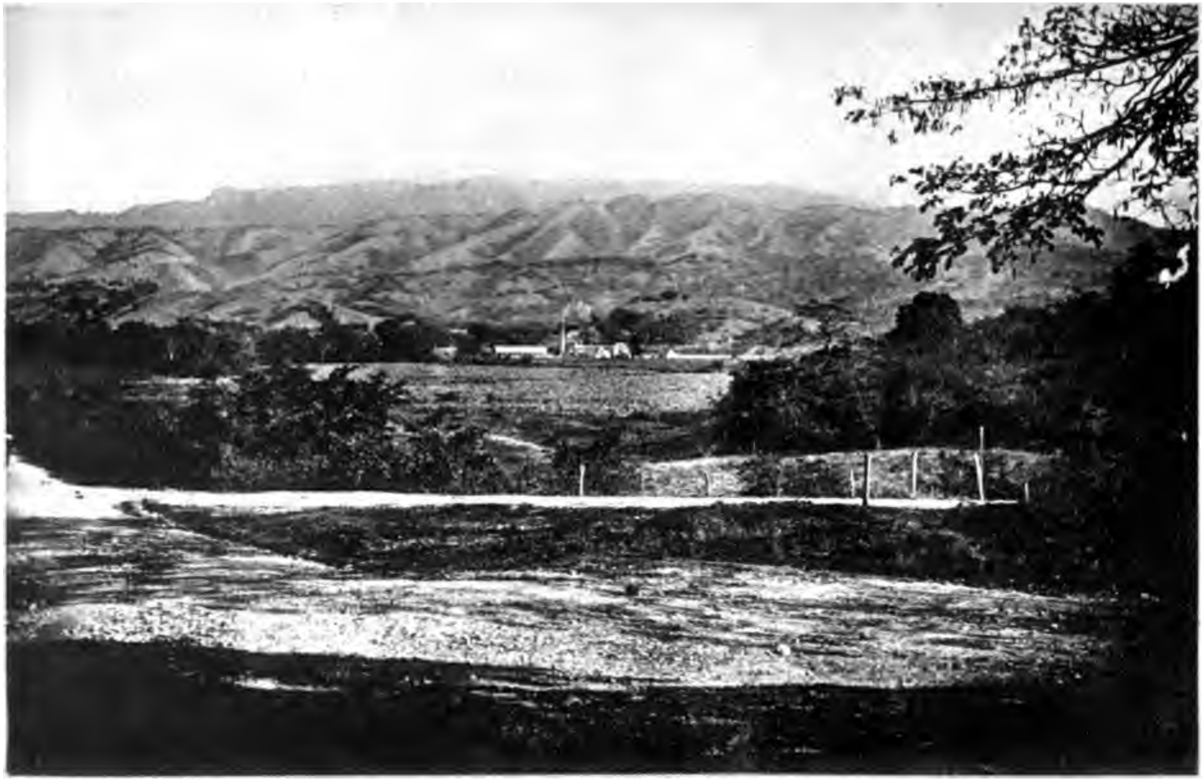
BLUE MOUNTAIN SCENERY, NEWCASTLE BARRACKS.



THE HELIOTYPE PRINTING CO. BOSTON

BLUE MOUNTAINS, LIGUANEA PLAIN AND PALISADES NEAR KINGSTON.

PLATE VII.



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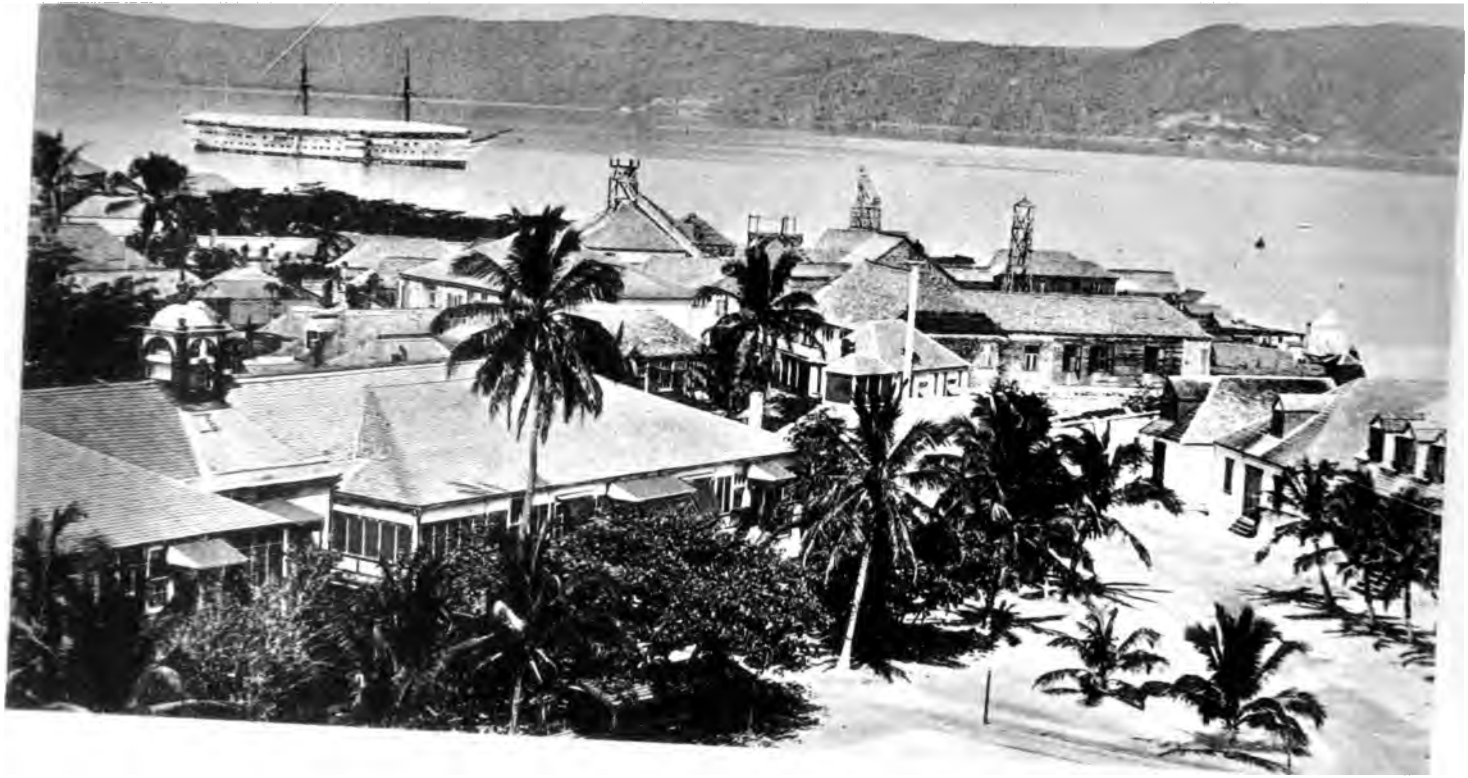
BULL HEAD MOUNTAIN, CLARENDON VALLEY.



THE HELIOTYPE PRINTING CO. BOSTON

COAST BORDER OPPOSITE PORT ROYAL.

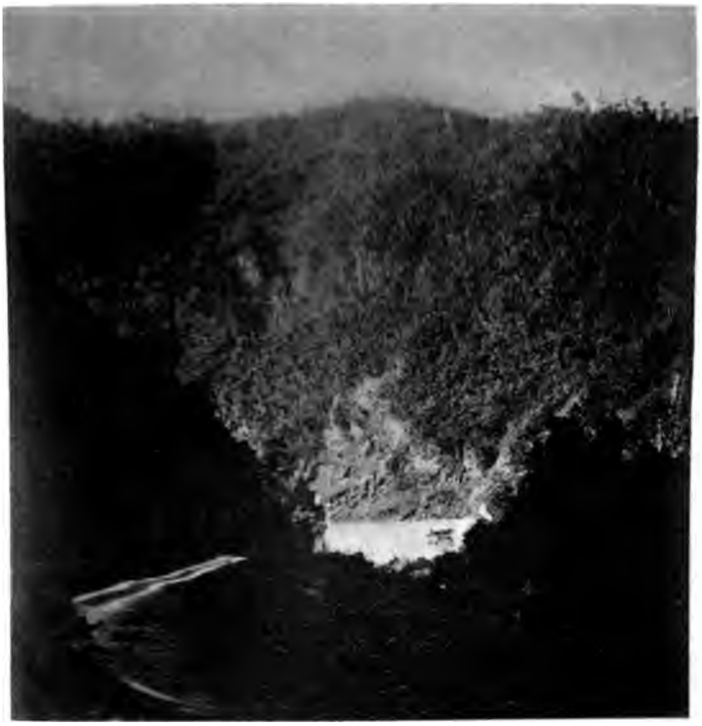


Fig. 2. Sink Hole Topography in White Limestone, St. Ann Parish.

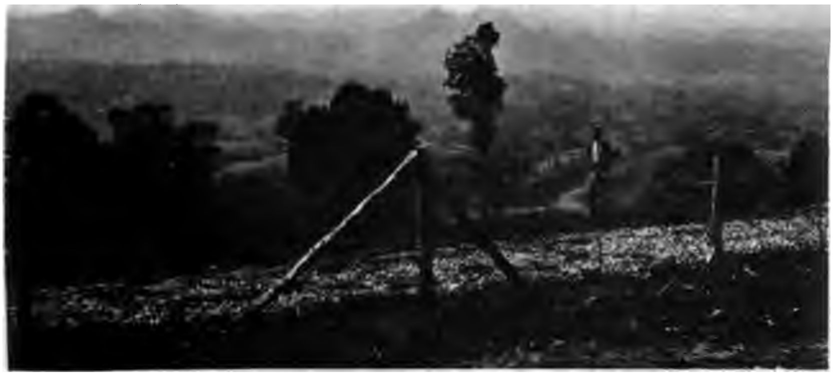
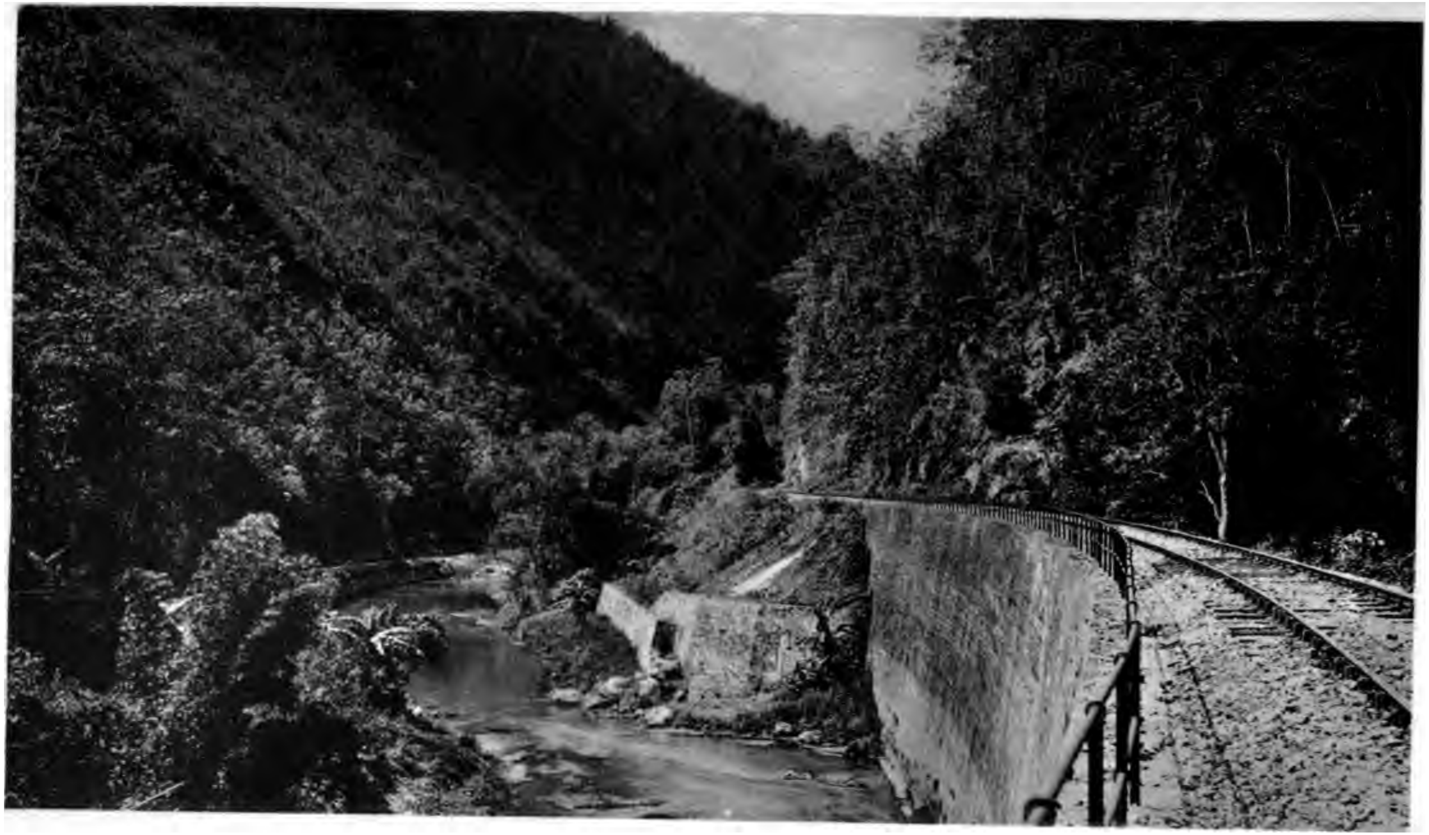


Fig. 1. A Central Basin near Catadupa.

THE HELIOTYPE PRINTING CO. BOSTON

PLATE X.



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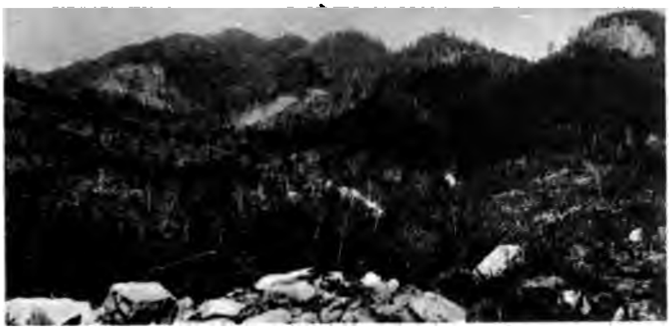
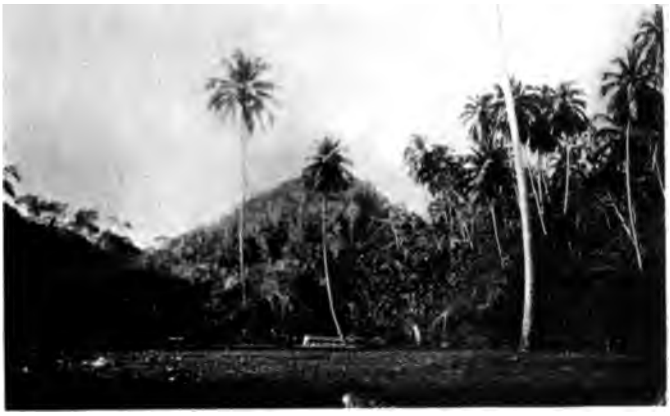
CANYON OF COBRE RIVER, BOG WALK.

1



Cockpit Topography.

2



Remnental Conical Limestone Hills

3

Remnental Hills, Westmoreland Limestone.

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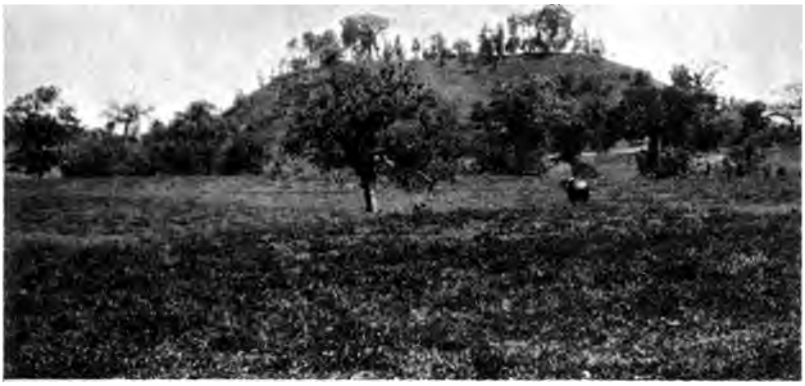


Fig. 1. Remnental Hill of Montpelier Formation. Morgan's Gut.

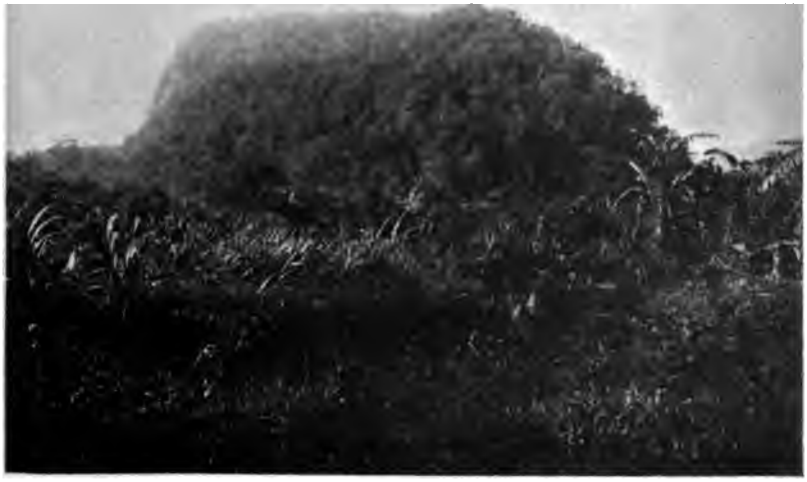


Fig. 2. Limestone Hills near Montpelier.

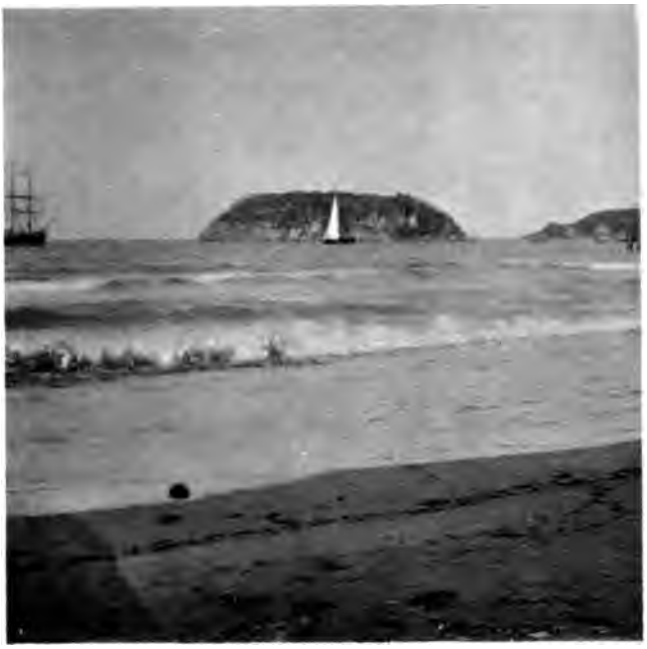


Fig. 1. Cabaritta Island and adjacent Mainland, Port Maria.

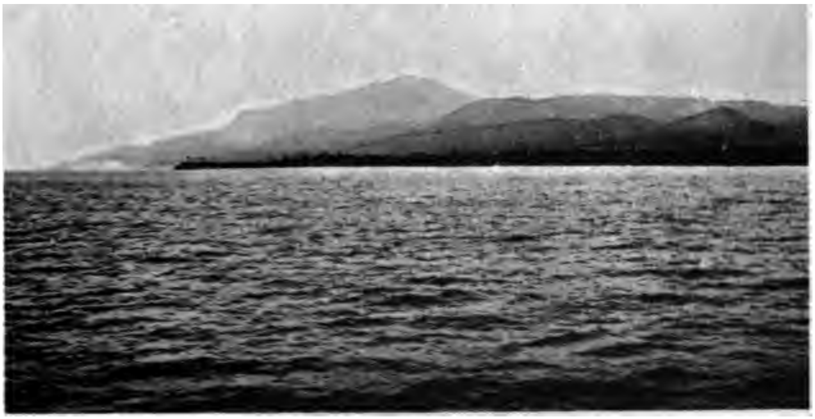


Fig. 2. South Coast near Yallahs Point, showing Lowland, Manchioneal Level, Yallahs Level, and White Horse Bluff.

1

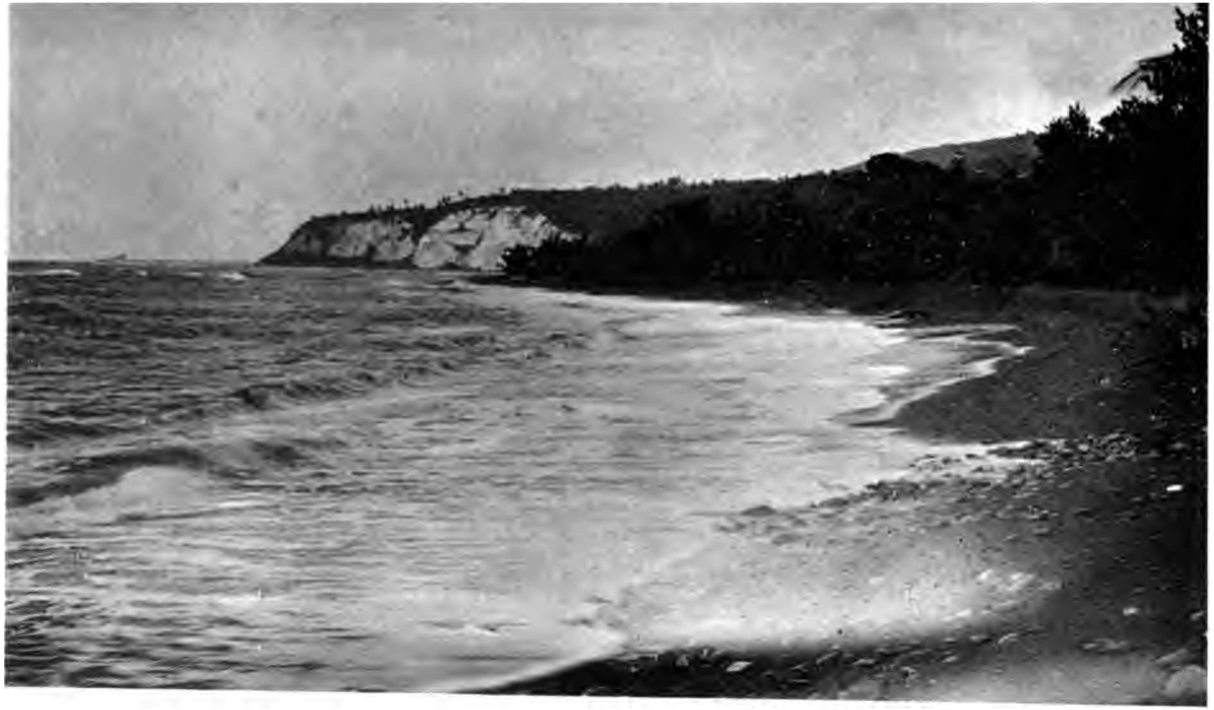
Back Coast Border and Coast Plain.

2

High Level Back of Porus.

3

Profile of Plateau Summit of St. Thomas Valley.



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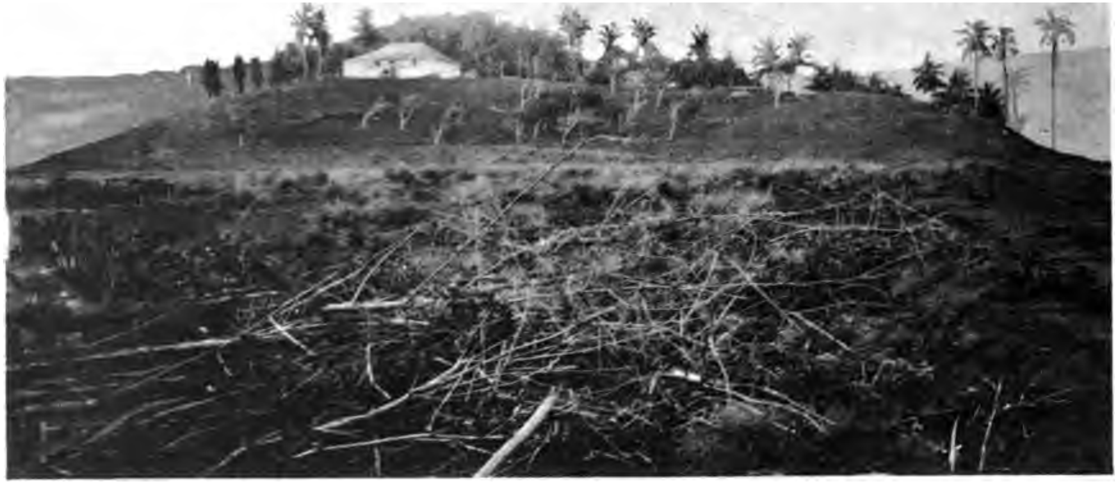
WHITE HORSE BLUFF AND BENCH, SOUTH COAST.



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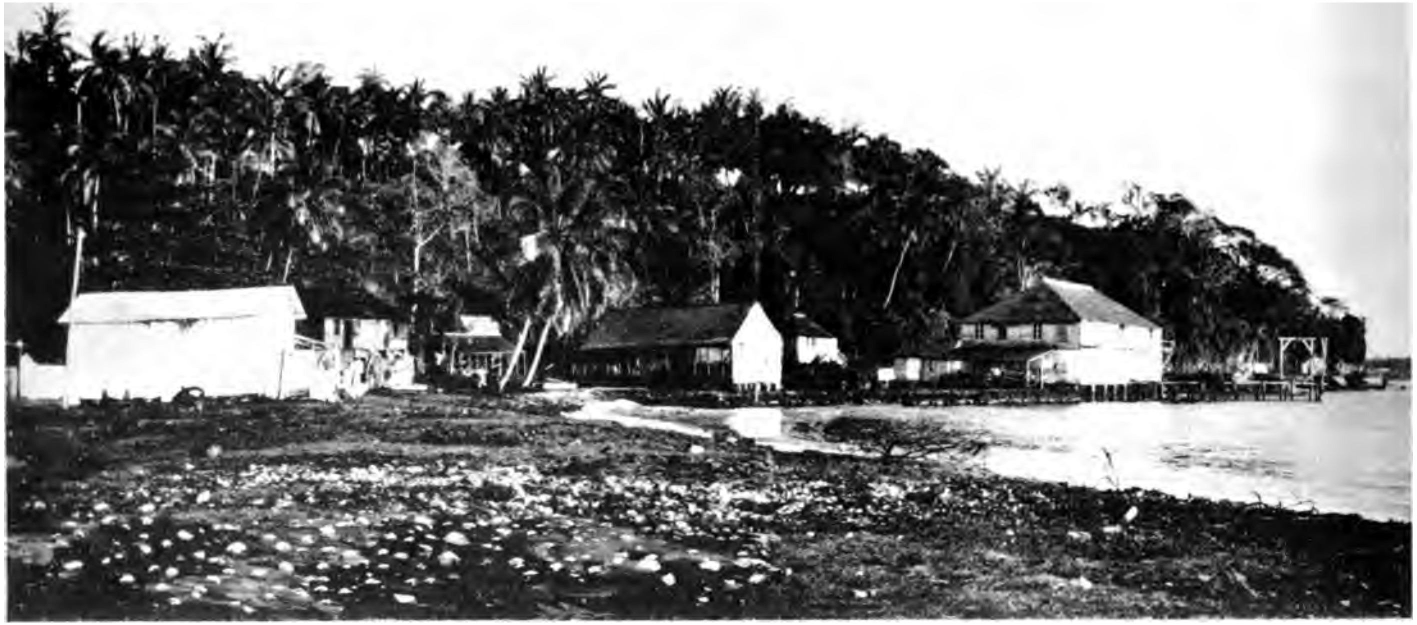
REMNANT OF 100 FOOT COAST BENCH NEAR NORTHEAST POINT.



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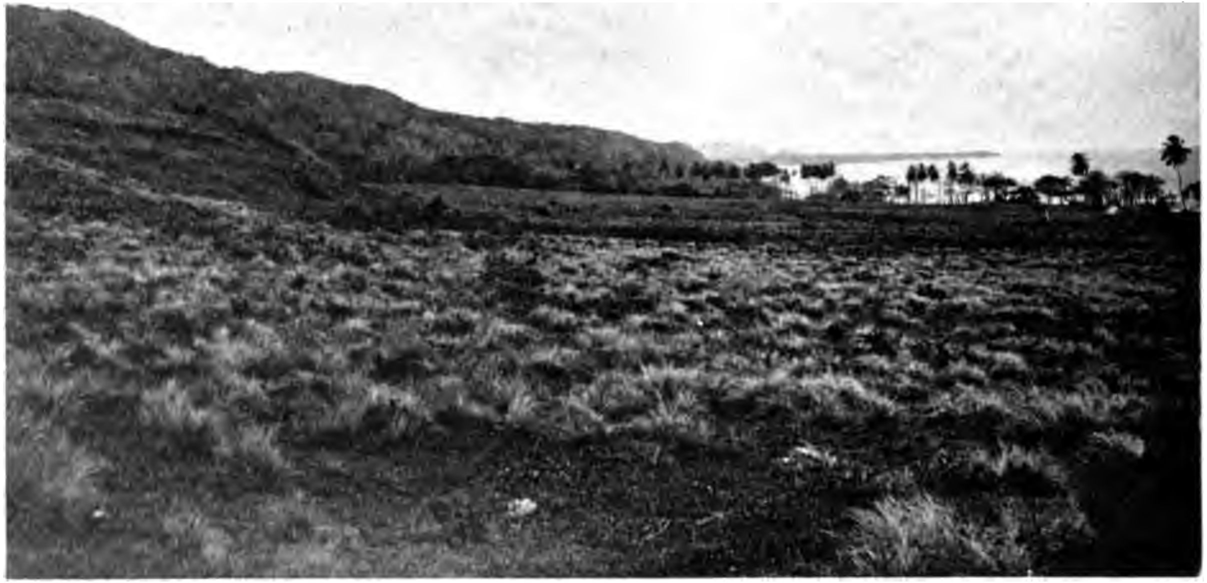
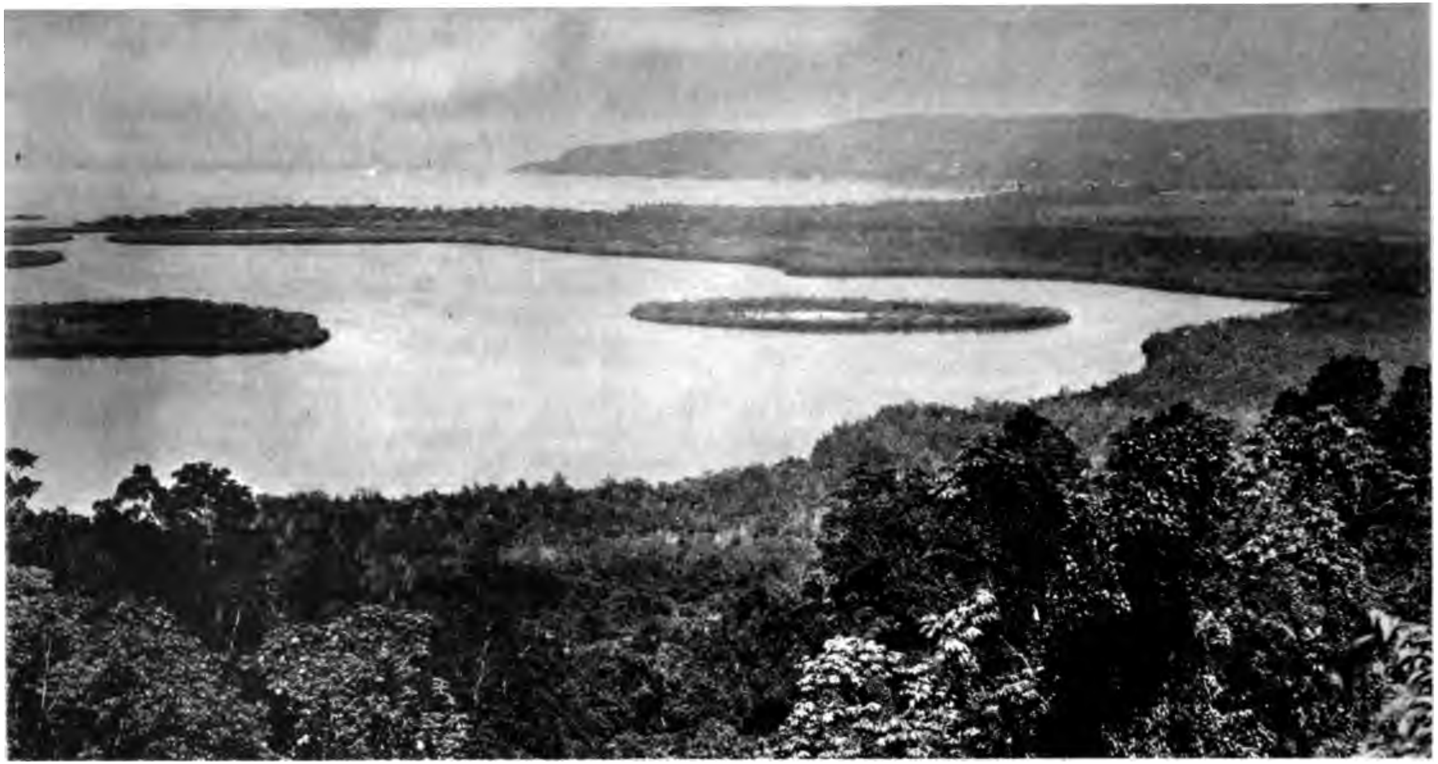
MANCHIONEAL BEACH, EAST END.



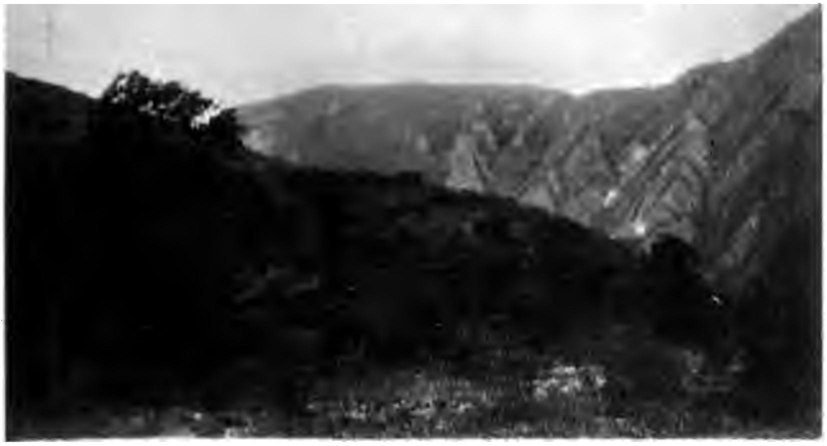
THE HELIOTYPE PRINTING CO., BOSTON

INDENTED COSTAL PLAIN BETWEEN MULATTO BAY AND MANCHIONEAL.



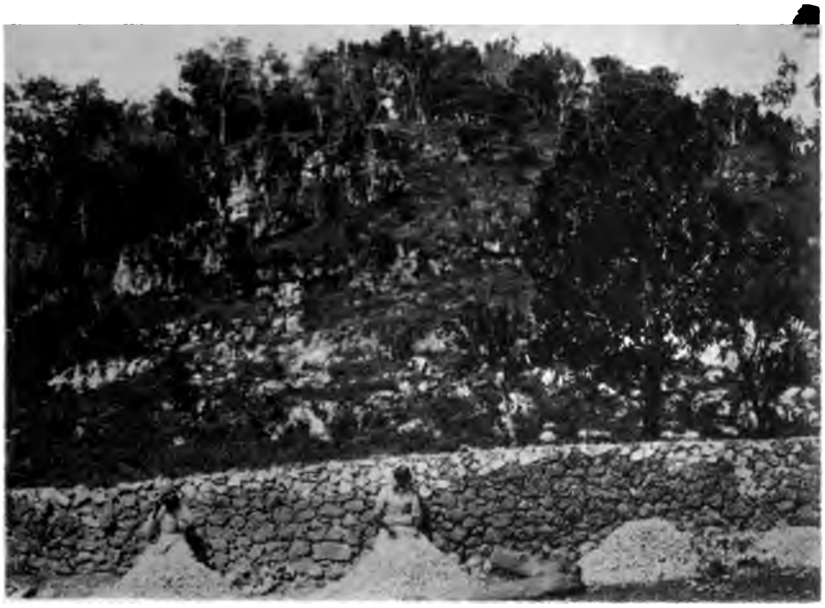
MANGROVE ISLANDS PSEUDO ATOLLS, MONTEGO BAY.

1



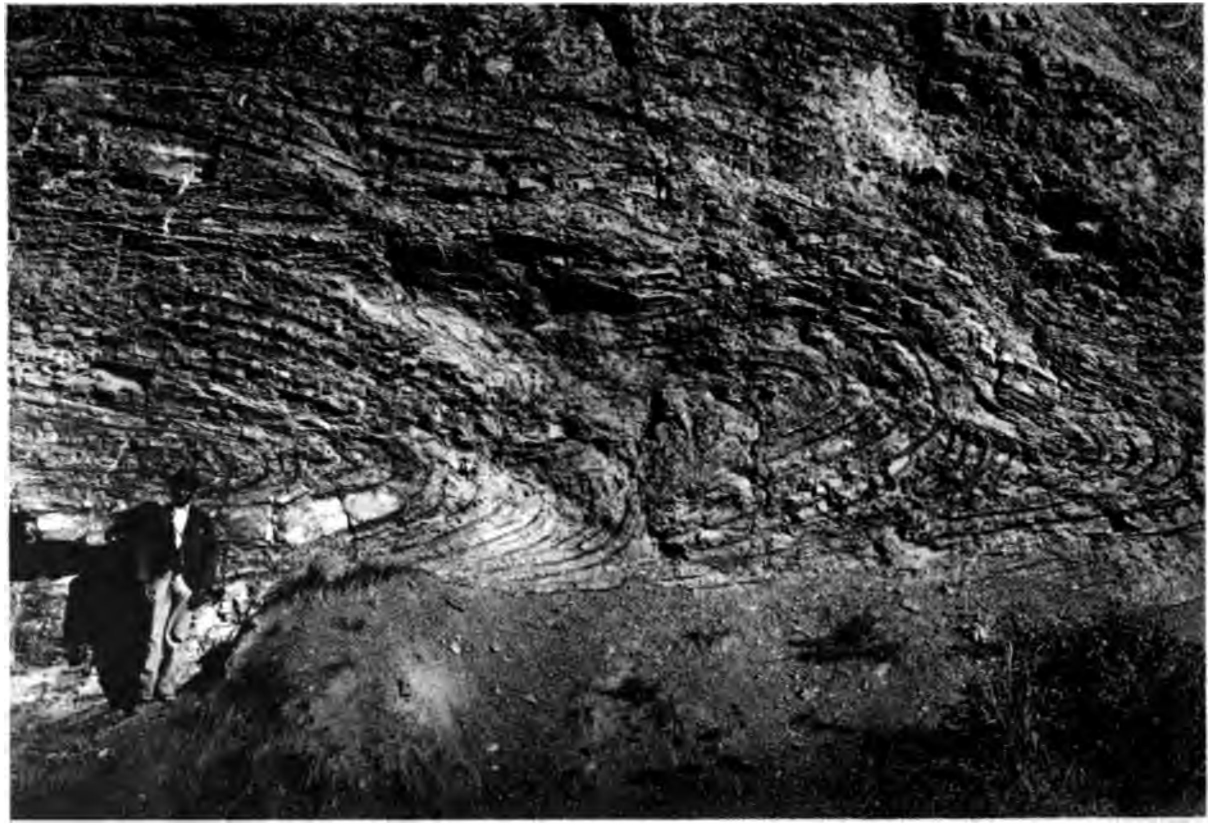
Folded Structure. Blue Mountain Ridge.

2



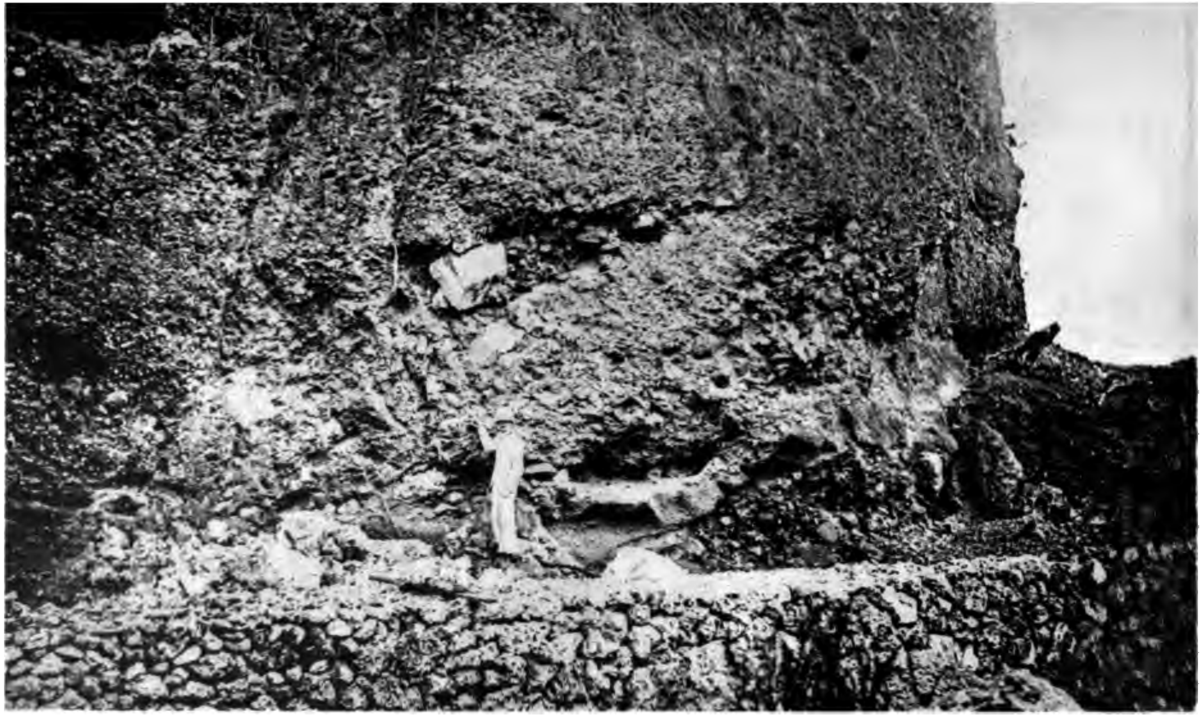
Surface Weathering. Moneague Limestone.

THE HELIOTYPE PRINTING CO. BOSTON



THE HELIOTYPE PRINTING CO., BOSTON.

OVERTHROWN FOLDS OF EOCENE RICHMOND BEDS.



THE HELIOTYPE PRINTING CO. BOSTON

RICHMOND CONGLOMERATES, GALINAS POINT.

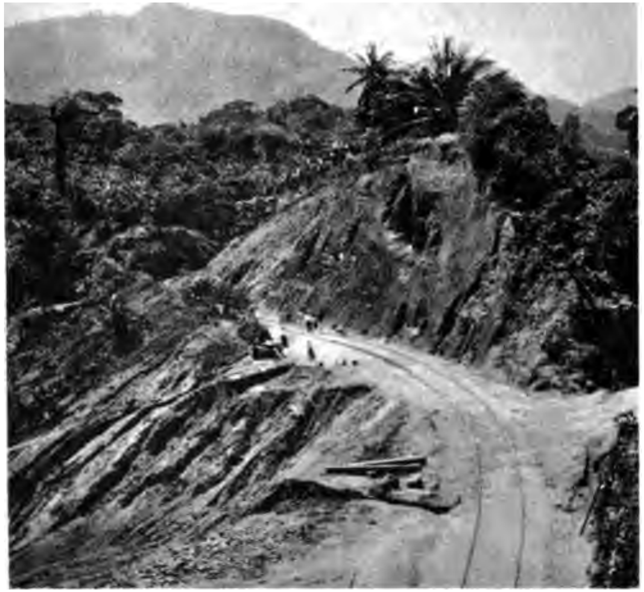
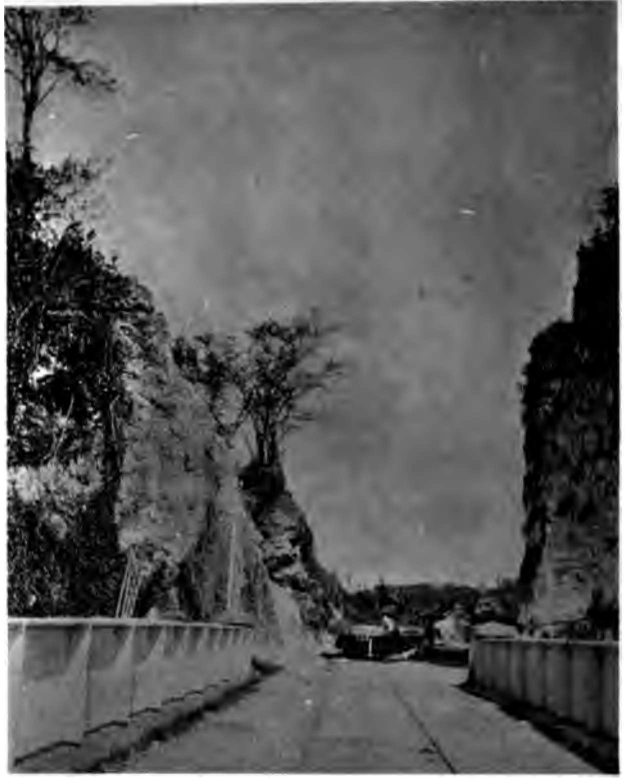
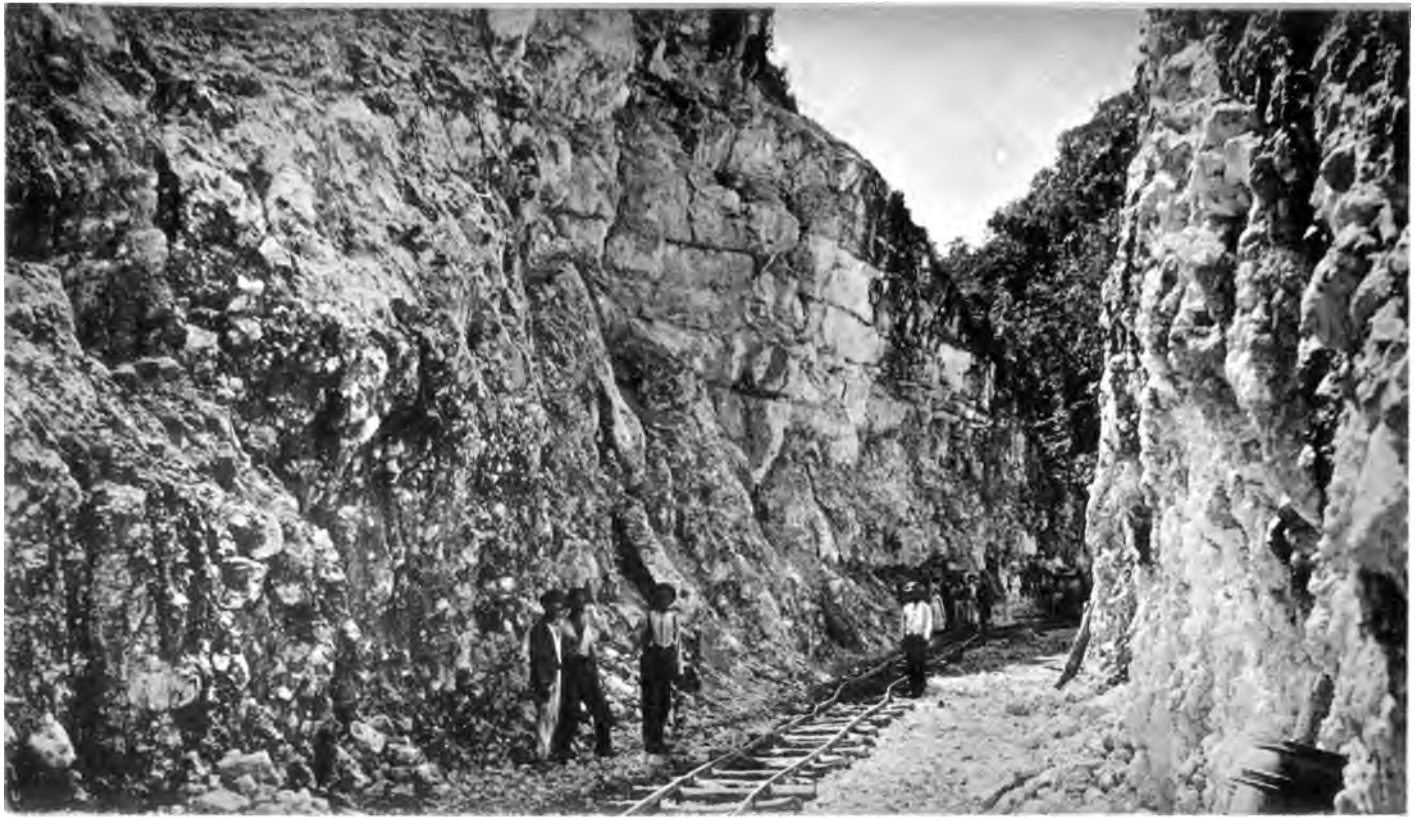


Fig. 1. Clays of Blue Mountain Series, St. Thomas-in-the-Vale.



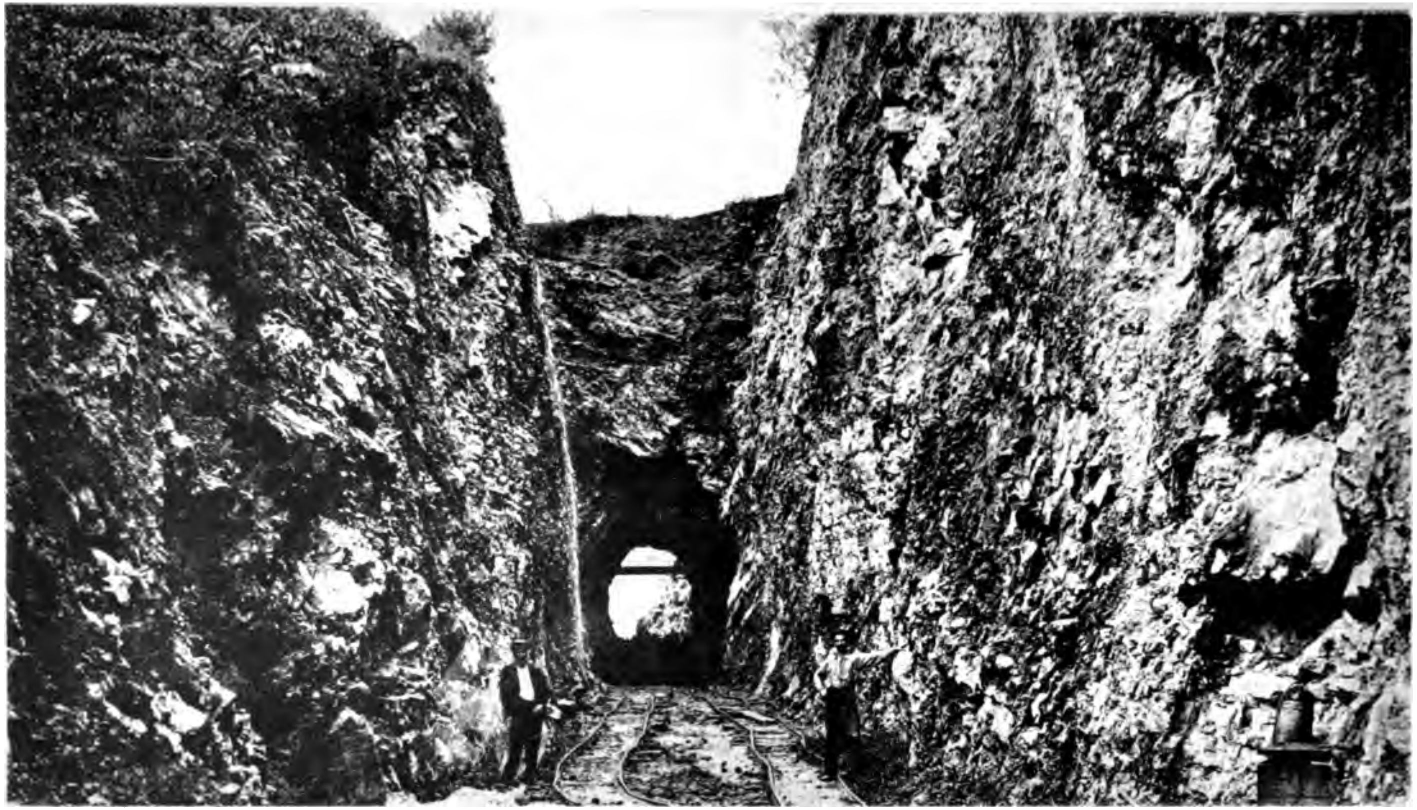
THE HELIOTYPE PRINTING CO. BOSTON

Fig. 2. Montpelier Beds near Port Antonio.



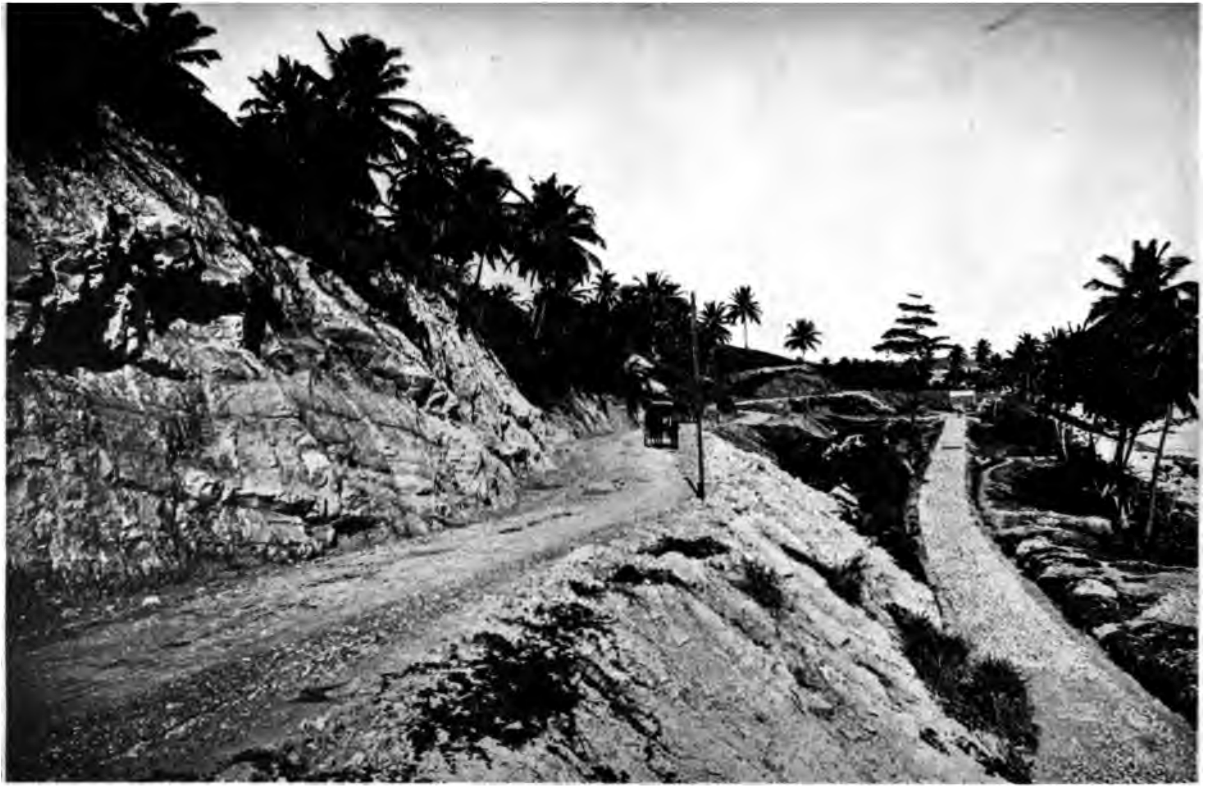
THE HELIOTYPE PRINTING CO. BOSTON

OUTCROP OF OLDER WHITE LIMESTONE NEAR IPSWICH.



THE HELIOTYPE PRINTING CO. BOSTON

UPPER PART OF OLDER WHITE LIMESTONES, MONTEGO BAY RAILROAD.



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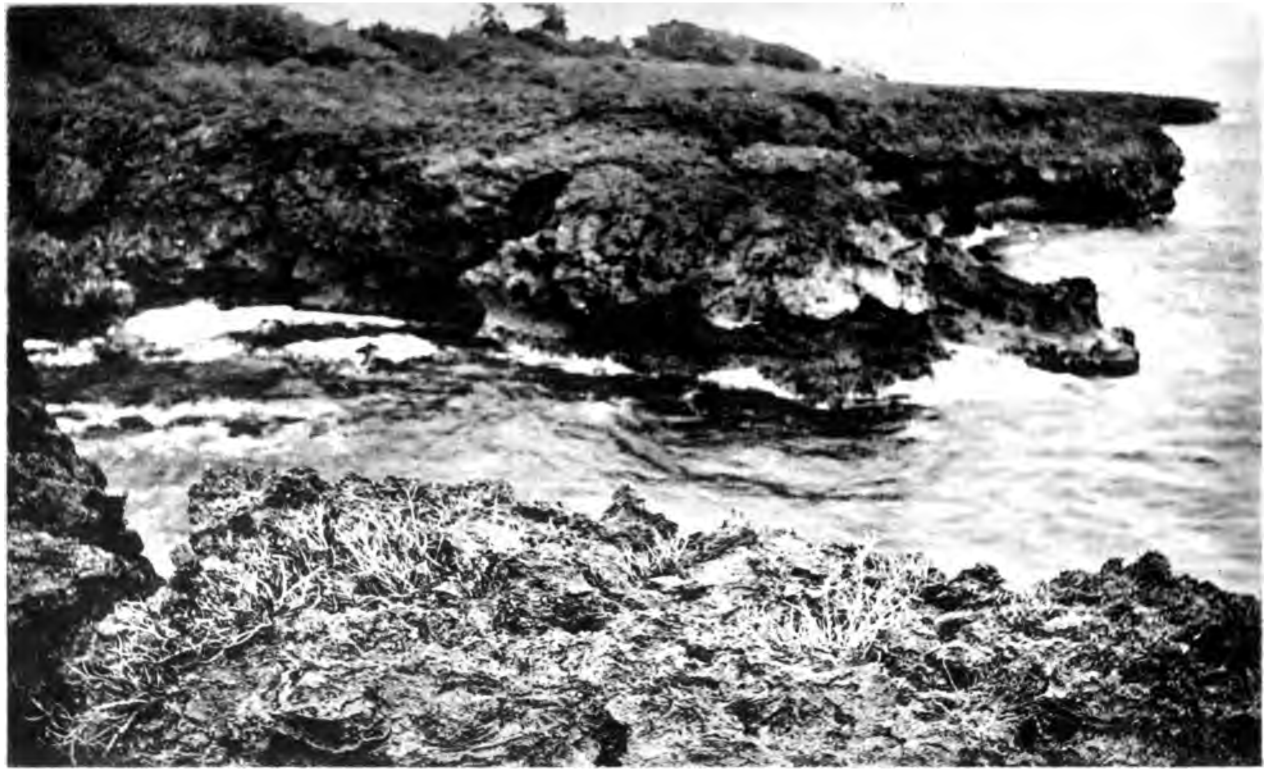
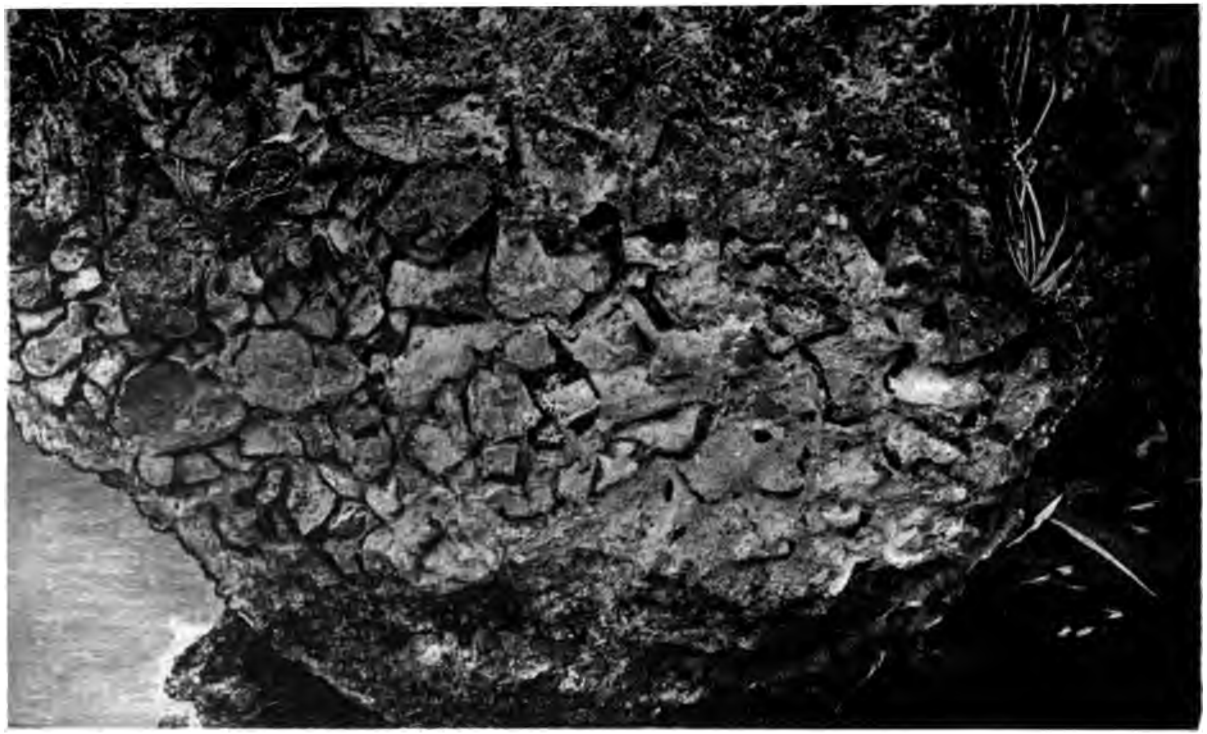
BUFF BAY (BOWDEN) FORMATION.



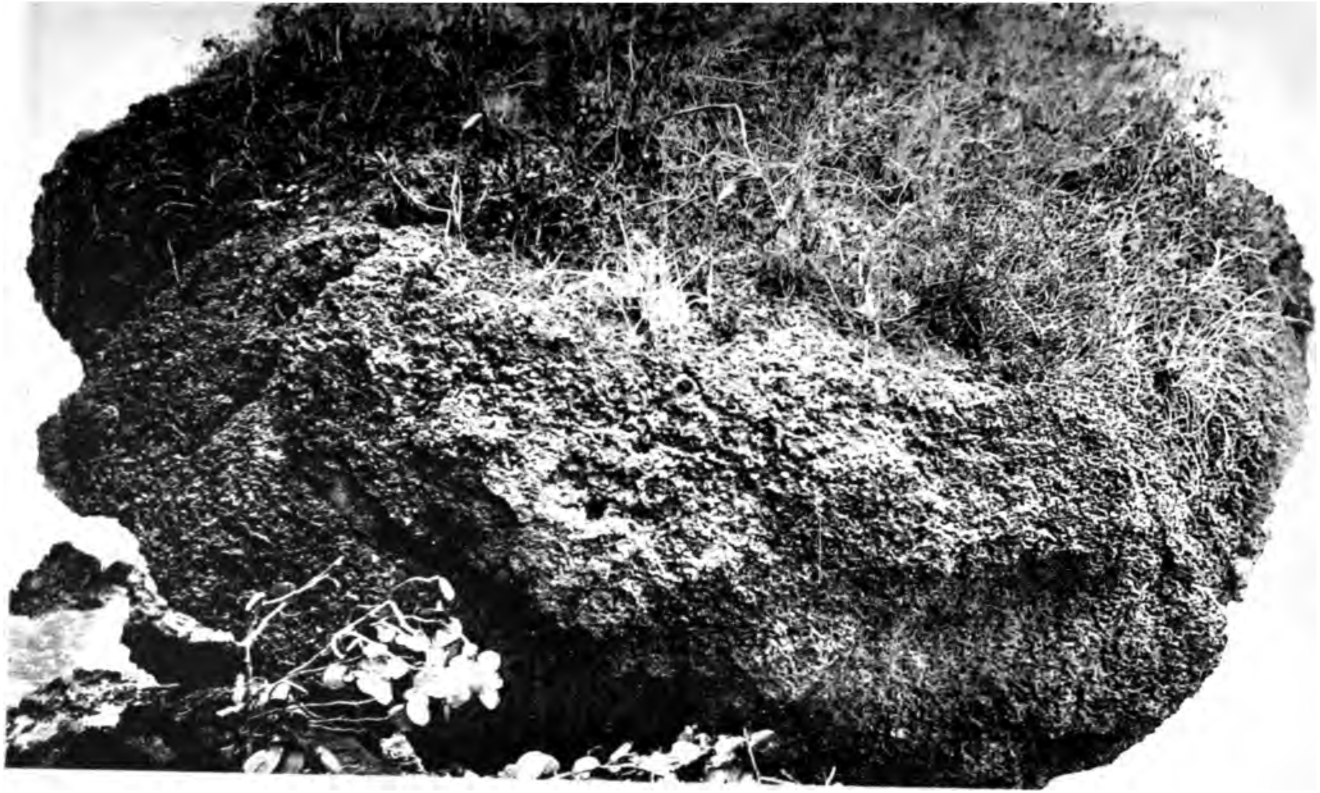
THE HELIOTYPE PRINTING CO., BOSTON.

LOWEST ELEVATED REEF, NORTHEAST COAST.



THE HELIOTYPE PRINTING CO., BOSTON.

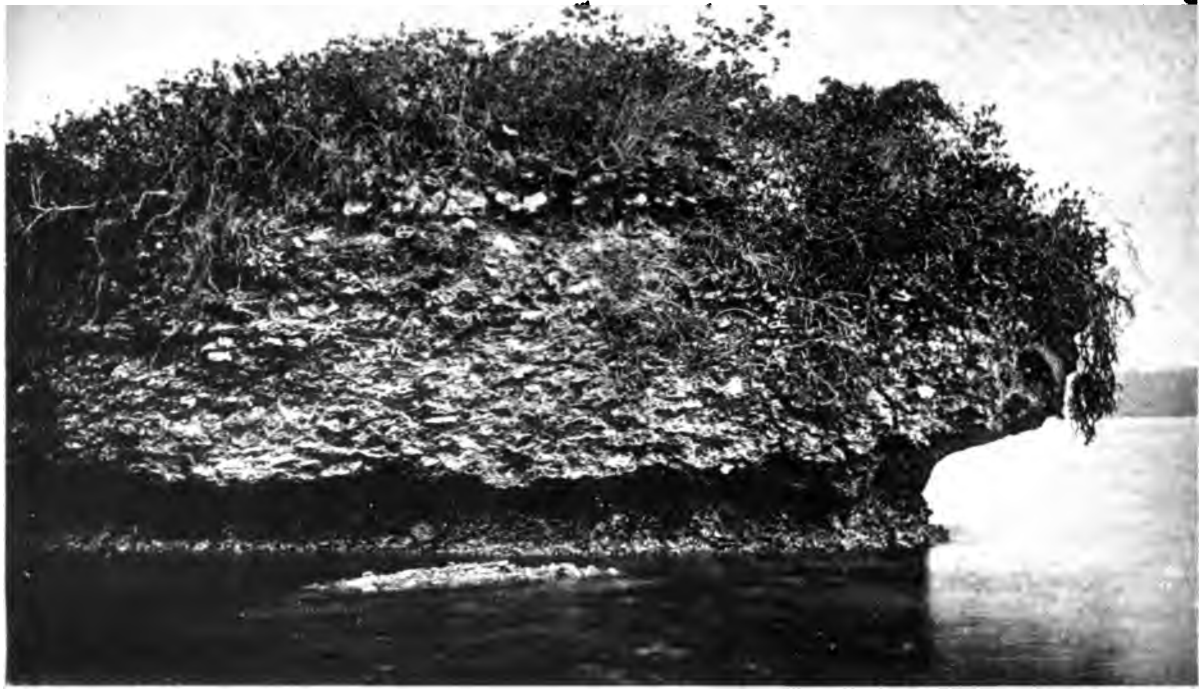
ELEVATED REEF ROCK, SHOWING LARGE CORAL HEADS.



THE HELIOTYPE PRINTING CO. BOSTON

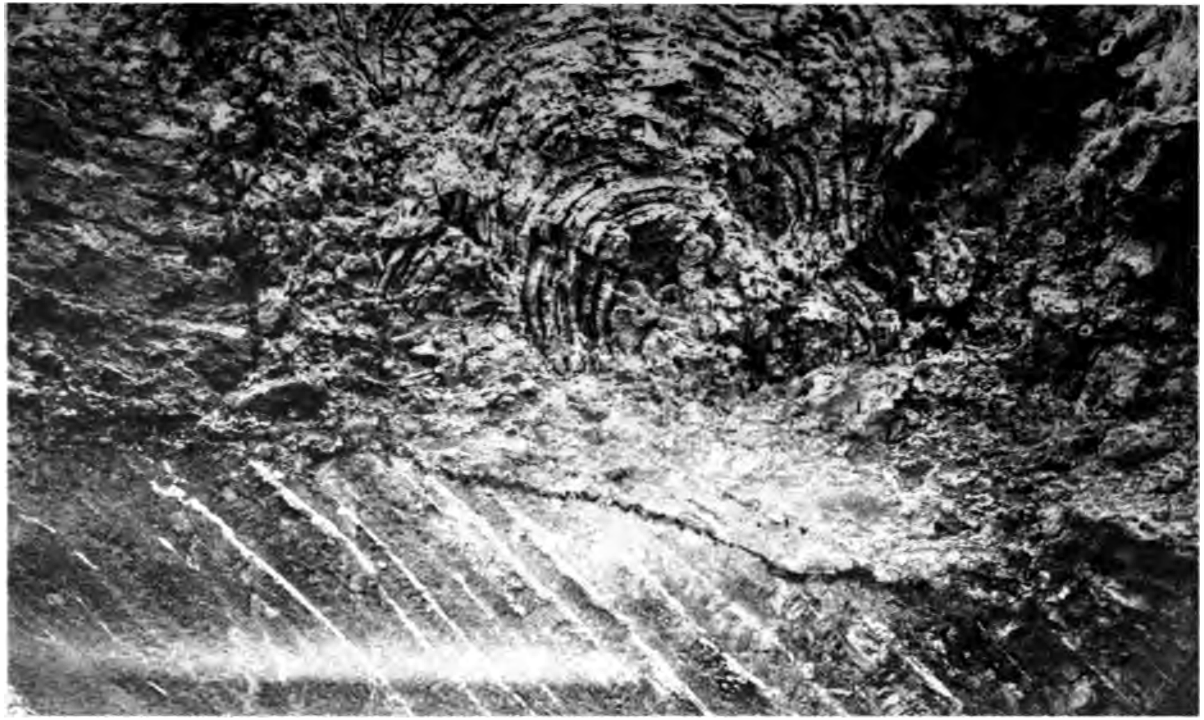
ELEVATED REEF ROCK, PORT MARIA.

PLATE XXXI.



THE HELIOTYPE PRINTING CO., BOSTON

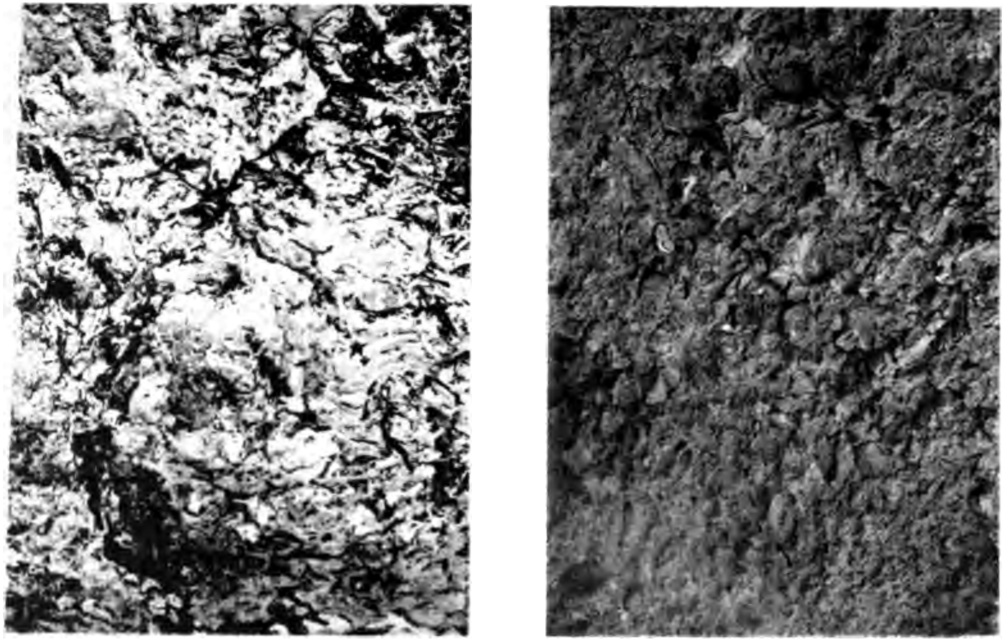
ELEVATED REEF NEAR PORT MARIA.



THE HELIOTYPE PRINTING CO., BOSTON

ELEVATED REEF IN CONTACT WITH FOLDED EOCENE STRATA.

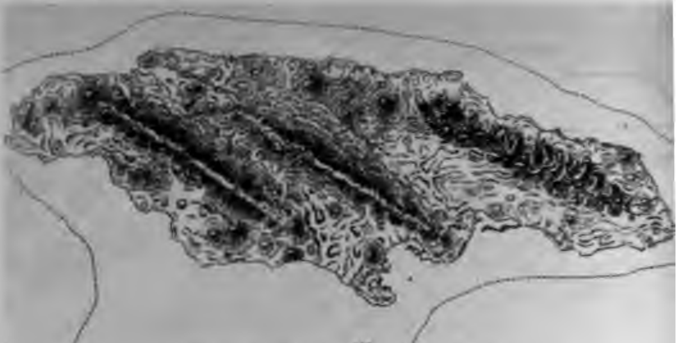
Plate XXXIII.



THE HELIOTYPE PRINTING CO. BOSTON.

ALTERED STRUCTURE OF OLD ELEVATED REEF ROCK.

Hill. Jamaica.



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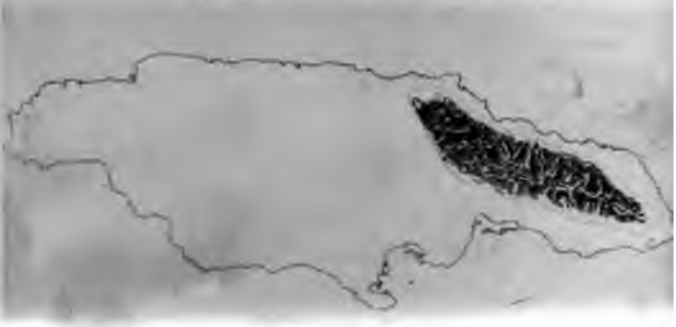
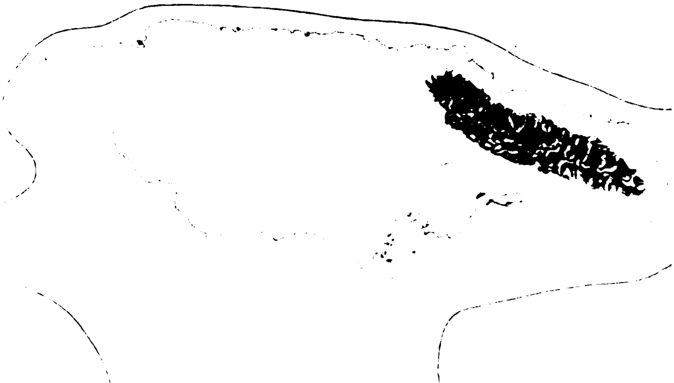
Hypothetical Old Land. Pre-Tertiary.



(2)
Restricted Land during early Tertiary Subsidence.

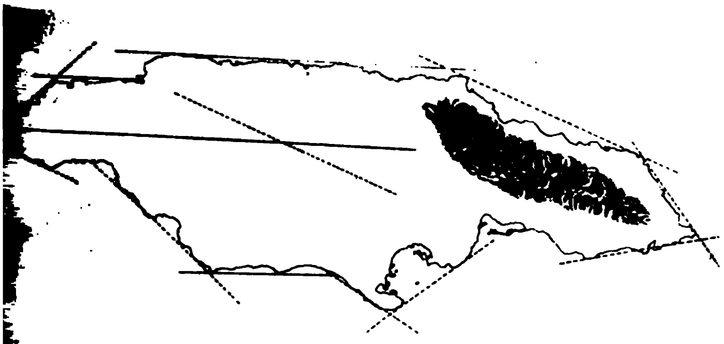


(3)

Mid-Tertiary Expansion.

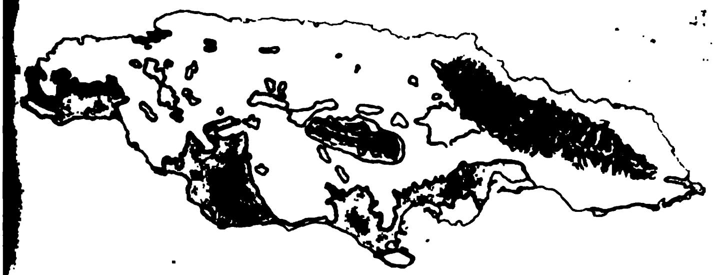
TOPOGRAPHIC

PLATE XXXV.



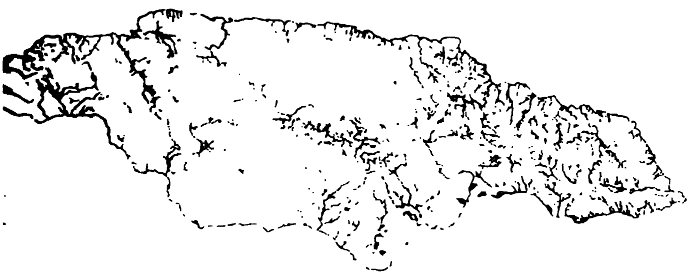
(4)

xes of old Tertiary Uplift, Dotted Lines. Axes of Mid-Tertiary Uplift. Solid Lines.



(5)

Late Tertiary Degradation.



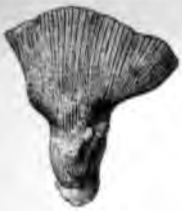
(6)

Drainage of Jamaica.

TION OF JAMAICA.

CO., BOSTON

Hill. Jamaica. PLATE XXXVI.



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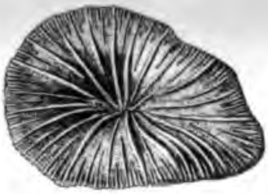

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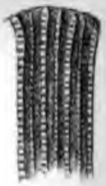

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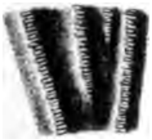

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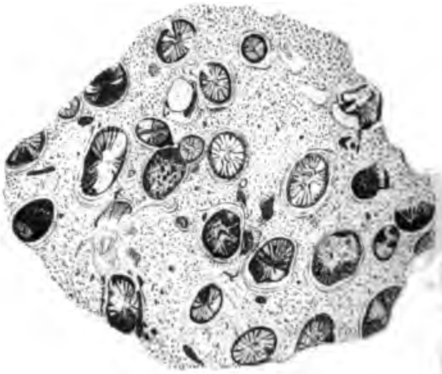

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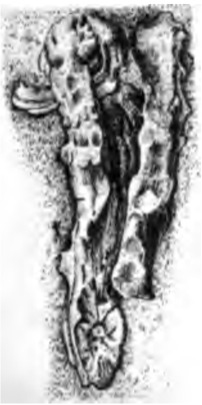

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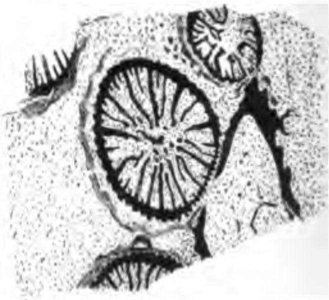

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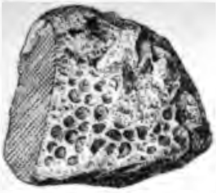
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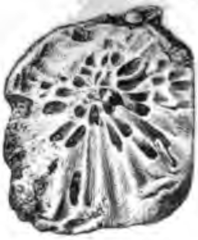
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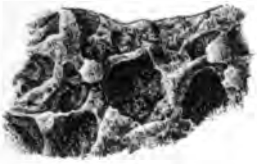
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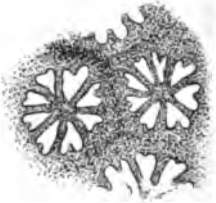
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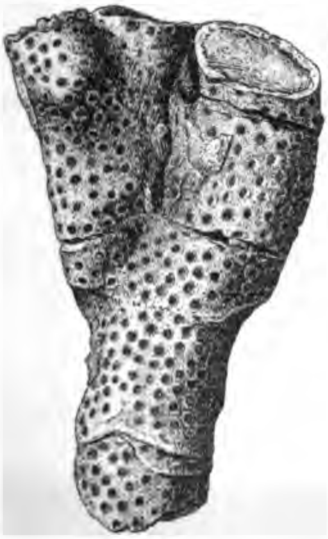
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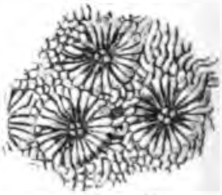
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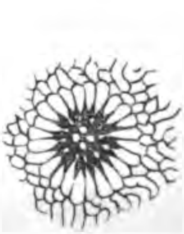
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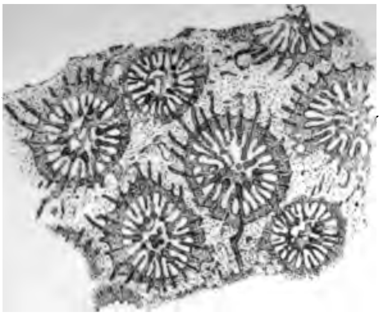

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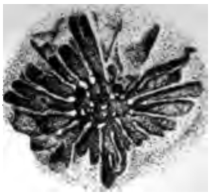

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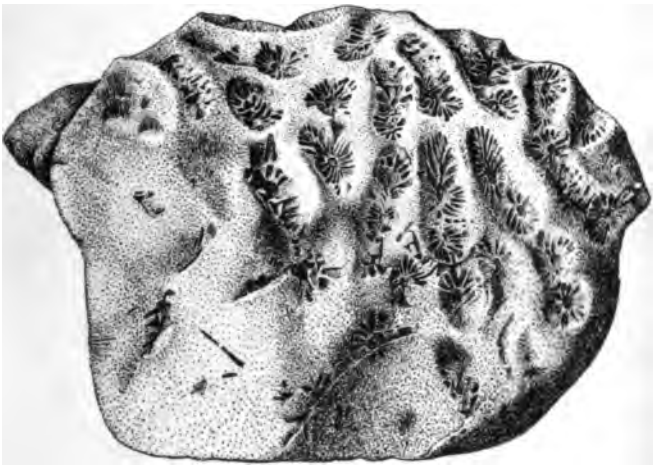

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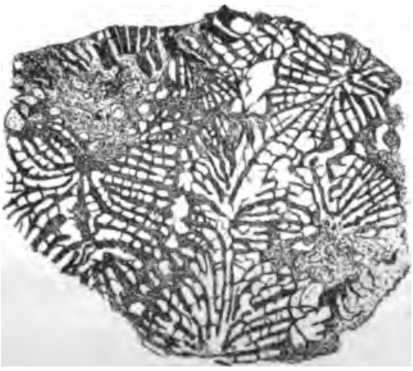

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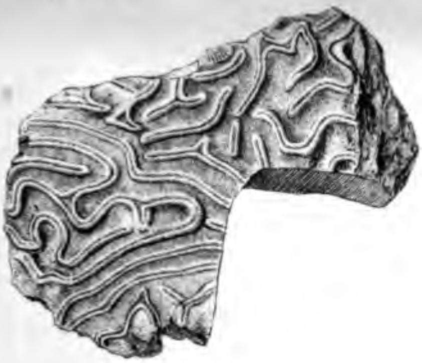
THE HELIOTYPE PRINTING CO., BOSTON



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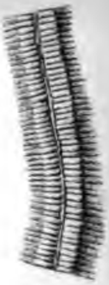

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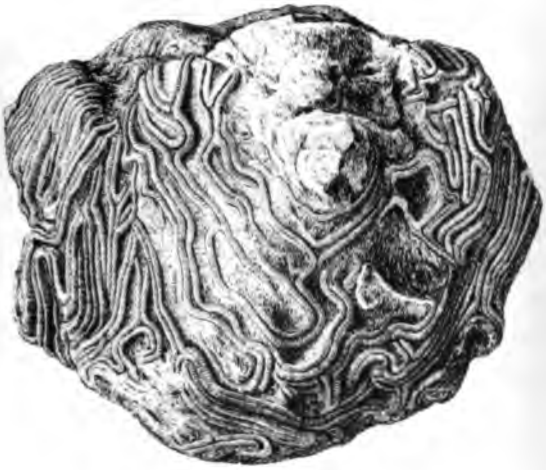

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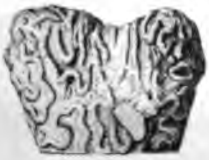

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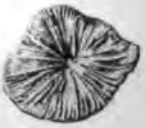

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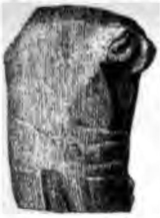

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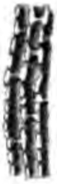

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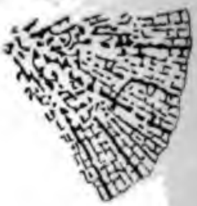

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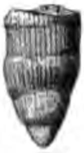

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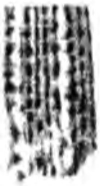

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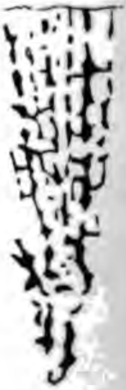

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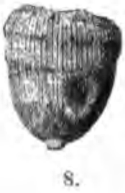

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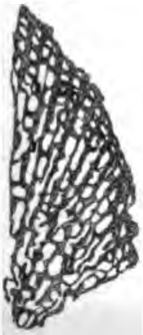

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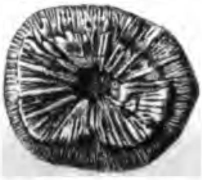

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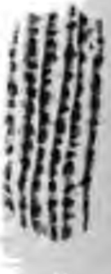
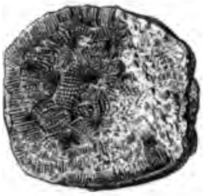


10.

Hill. Jamaica. PLATE XLI.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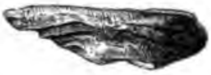
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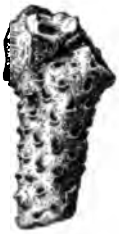
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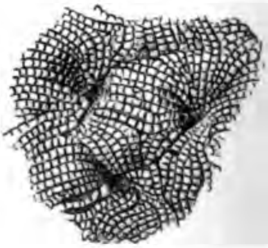
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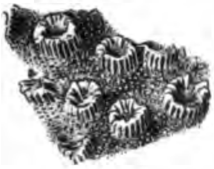
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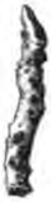
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